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PSYCHOLOGICAL OPTICS

Samuel Renshaw, M. A., Ph. D.

P S Y C H O L O G I C A L   O P T I C S

by

Samuel Renshaw, M. A., Ph. D.

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by Samuel Renshaw, M. A., Ph. D.
Ohio State University

Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

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WHAT CAN EXPERIMENTAL PSYCHOLOGY CONTRIBUTE TO OPTOMETRY?

Vol 1 No 1

Vision and visual problems are common ground for many divisions of science. In this first paper of a series of "talks to optometrists" it shall be our job to show how psychology plays its part. Physics, physiology and neurology describe what is known about the eye, how it is arranged for the reception of changes in the patterns of light and how these physical events in the retina produce impulses in the sensory nerve fibers. These impulses then pass to the brain and on to certain of the effector organs of the body, muscles and glands. From the effectors other proprioceptive organs pick up the results of the contraction or secretion and relay the impulses back to the cord and brain. Thus is completed the organic circuit. Volumes could be written by scientists summarizing our present knowledge about each phase of this most interesting and important process. Other volumes could be written on the numerous problems relating to vision which are poorly understood today, if at all. Each of the sciences makes its own studies of the process, working from its own point of view, using its own tools, devices and methods; no one tells or can tell the complete story. Each borrows much from its fellows; altogether they can give the most complete and truthful picture of the process available to any human being.

Most optometrists are required to know and stand examinations on the physical and mathematical principles involved in the laws of lenses; geometrical and physiological optics, etc. The anatomy and histology of the eye is taught in all the leading schools. Psychological optics on the other hand, is almost universally neglected. Yet, it is a most important factor in every case seen by the practicing optometrist. In the most simple way possible let us put it this way: People come to you but for one purpose -- to secure for themselves clear and comfortable vision. No matter how exacting your instrumentation, or how clever or how skillful your diagnosis, prescription or treatment, your lenses will not be worn if they do not yield to the patient comfortable clear vision.

Now just what constitutes "comfortable, clear vision?" Can it be lacking and the patient show significant corneal or lenticular aberrations? Can it be lacking and accommodation and convergence yet be entirely adequate? Can vision be uncomfortable and not clearly and sharply resolved when all the mechanical factors of vision are in such order that the patient should see comfortably and well? I am certain that from your experience you can readily answer all these questions in the affirmative. And this leads us at once to our first generalization -- one of the things which will help us understand better what psychological optics is, what we can do about it, and what it can do for us.

This generalization is that a large part of seeing is not done with the eyes at all. Vision draws heavily upon the other sense modalities, particularly the skin, the kinesthetics (muscle, tendon and joint sense) and the ears. Whenever I say, "This iron ship's anchor looks so heavy I doubt if I could move it from the sand" -- I am speaking figuratively. Nothing ever really looks heavy. "Heavy" is a judgment. We make it when we try to overcome the inertia of a mass by the shortening of certain groups of our muscles. Similarly other senses borrow from vision. Much of what we hear derives from watching the movements of a speaker's lips, his gestures, the play of his facial muscles. Since the afferent impulses from sight, hearing and touch are all correlated in the midbrain, and since in all the ordinary affairs of everyday life the perceiving of things is participated in by almost all of our sensory-motor functions, we hear more and more discussion of the unity of the senses, and less and less about each one, separately considered from the others. When you read or are told that "85% of all your impressions come through your eyes" set it down as a statement which is false, unproven and unprovable. Eyes are important, most certainly.

but there is no good reason why we should tell untruths about them It is a psychological fact that everyone sees more than is furnished by stimulus objects This is another way of saying that the observer contributes much to the process set up by various patterns impinging upon the retinae We not only thus supplement what is physically present to be seen but it is likewise a well-known fact that we may suppress large portions of the field comprising the stimulus pattern.

Let us take, for example, the case reported by Dr Purdy, a prominent psychologist who has contributed much to psychological optics (Psychological Review, 1935-1936). A girl on being shown three small dots in the shape of a triangle and asked to fixate a fourth dot in the center, reported that the three dots ran toward the center and fused into a single dot at the point of fixation No matter what interpretation is placed upon this phenomenal experience one fact is clear: The retinae are being stimulated continuously by the three dots. The fact that they do not in experience remain in the same relative position as they are found on the retina indicates that a process of simplification, suppression, or reduction of detail in the stimulus pattern may be added to the experience by the observer himself Instances of this sort clearly indicate that psychological optics has its own problems Many interesting and important similar instances could be cited to show that no complete account of seeing can be rendered without the assistance of the description of the psychological aspects of the process

Interesting also is the fact that we see things not on the retina, not in the brain but out there in space Why should this be? Can we find the answer to this question in text books dealing with physics or geometric optics? Can we find it in physiology or neurology? Then obviously we must be dealing here with a fundamental problem which belongs specifically to the field of psychological optics The position in space of an object, its size, shape relative brightness, color, motion etc are seen by an observer in a way not predictable by anything we may deduce from the size position, shape etc of the hypothetical retinal image Before their habits are fixed most children are able to read print upside down as well as right side up Stratton, Peterson Ewert and others have worn prisms inverting the visual field with the result that their movements, at first seriously interfered with, soon are made as if vision were normal. Professor Young constructed a device for the acoustical transposition of the ears and soon formed the habit of properly localizing the source of the sound of pedestrians passing him from the rear, bells ringing or persons calling to him. Extensive experiments on localizing points stimulated on the skin have shown that if the localizing is done upon an artificial arm lying on the table in front of the subject and his real arm is stimulated in other positions with his eyes closed, the stimulus comes to be felt as if it occurred at the point of localization -- that is where we do something about it! Thus we see that the nature and kind of motor adjustment made by an individual is capable of completely transforming the customary response to a stimulus particularly into something quite different from the thing we might ordinarily expect. This fact of external reference proved to be an important discovery in psychology It shows us that seeing objects in space outside the body is a common habit, learned from early infancy, and capable of considerable modification through training. It also shows us that this important province of vision belongs to the psychologist's division of labor for we can find no satisfactory answers to the many questions we want to know about them in the books written on vision by competent men in other related fields of science We might even say that psychology has as its sphere the science of seeing, whereas physics and the biological groups are concerned with the mechanics of vision Seeing is something more than vision although vision is a most important and essential part of seeing.

Let us now consider another phase of this relation of vision to seeing. The curved surfaces of the retinae comprises a punctiform distribution of some 120,000,000 rods and some 7,000,000 cones, according to the estimate by Krause The number of fibers in the optic bundle is such that each incoming fiber must conduct the impulses to the brain arising originally from the stimulation by light of about 4,000 of these very small photo-sensitive cells If to these considerations we add the fact that the light-energy-density relations in the stimulus object "out there" are not constant when the light excites these cells

and that cross and longitudinal relations in the optic bundle represents a further distortion of the "real" object out there, then why should not a visitor from Mars inquiring about Earth-creatures and their eyes reasonably ask, "How can you see as a continuous, unitary straight line this solid black line on a white background?" The appeal again must be to psychology. Nothing that we can find from our knowledge of the structure of the retina, the optic bundle or the nature of the conduction of impulses in nerve, can possibly give us the answer. And if in the light of everything that we know about rods and cones, about the nature of nerve conduction, etc. is taken into consideration and we try to answer the question: What is the physical mechanism which enables us to discriminate small differences in the intensity of illumination? We are forced to conclude that no satisfactory answer to this question can be found. The only explanation which seems to fit the facts must involve psychological consideration.

If our friend from Mars is an exceedingly inquisitive fellow he would undoubtedly list many additional questions about simple cases of seeing such as the following. Before me lies a small pad of paper three inches by five inches on the extreme right corner of my desk. I know that the angles of this pad are all right angles but if I want to draw for my friend from Mars a picture representing what I see as I look at the pad, I do not dare to draw four right angles. I can only see the pad as comprising four right angles under a very narrow set of conditions. This is to say it will have this appearance when it is directly in front of my eyes and on the line of sight and when it is seen under the influence of certain background and foreground relations. In fact, the size angular relations and relative position of the "retinal image" do not vary in any constant way with phenomenal experience. Imagine what would happen if we always saw things (and reacted to them!) as they appear on the retina? The four dinner plates to the right of you then become four increasing ellipses, the final one being much longer than wide. Ours would be the fate of the inexperienced child, who, on seeing an artist's drawing exclaimed "See, elliptical wheels on the cart . . ." and then naturally fell to wondering what would happen, especially since the rear ones were larger than the front wheels, if the thing should start! The fact that if vision were a direct-copying process, life and experience would be for us a hopeless confusion, seems to be ground enough to justify our serious attention to the problems and accomplishments of psychological optics.

In subsequent papers these informal talks will deal especially with a wide variety of problems arising out of the facts derived from the psychological study of seeing. We shall deal with questions relating to why things look as they do; to stereoscopic and pseudoscopic vision and to the seeing of the third dimension; to visual apparent movement; to brightness discrimination and the problem of intensity; daylight and twilight vision and visability curve; color vision and color anomolies; visual perception and the problem of isomorphism; visual acuity and its measurement; the retention and recall of complex visual impressions, and on the training of the eye to see. We shall hope to show as we go along that scores of able workers in experimental psychology in various parts of the world have accumulated a large body of facts and that these facts are of the utmost practical importance to optometrists and to all others interested in the science of seeing. It is safe to predict that future developments in optometry will come to deal more and more with the psychological aspects of visual insufficiency. We shall hope that this series of short papers may serve to direct your thinking and study along these lines.

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

 Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

THE IMPORTANCE OF POINT OF VIEW

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Before undertaking an examination of results and theory in psychological optics there are some very necessary preliminaries with which we must deal. Were we to fail to do this, no matter what our intentions and efforts, we should not be very successful in making clear the meaning of the principal accomplishments in this field. I refer to the primary importance of point of view.

Progress in any division of science generally follows from the setting up of a set of postulates. These serve to set the limits of our operations and assist in the proper formulation of problems and methods.

Chemists at one time worked on the basis of a set of postulates which held that everything was some combination of four elements - earth, air, fire and water. There was another "element" too, but very little was openly expressed about it. Logic and speculation supplied a hypothetical frame work of affinities and repulsions among certain of the elements. This was the historic age of alchemy. Very little progress was made in gaining a better understanding of the chemical world, so long as the limiting concepts of the alchemists were accepted and followed. In fact chemistry was not chemistry at all, except perhaps in name.

One of the many deficiencies of such an approach to the study of things and processes in nature lies in the fact that mysticism and teleological expletives are introduced in order to make the assumptions cover the observed cases. Thinking becomes finalistic, classificatory. Like the old instinct doctrine, name and classify an act and your problem is solved. No further investigation is needed or wanted. The arm chair, debate and easy common-sense logic take the place of the laboratory and rigid proofs.

It took the chemists a century or more to free themselves of the blinding, hampering influences of the earlier, wrong point of view. But by systematically revising their total concepts, refining and extending methods, the creation of better working tools, the science of chemistry emerged from alchemy and natural philosophy, and in so doing produced results which have revolutionized the economic order. Modern chemistry has radically changed the whole picture in the study of the physiology of body functions. Each year its horizon widens and the scope of its service becomes greater and more important.

Psychology and the biological groups are gradually emerging from their own infancy - the age of poorly chosen postulates, pseudo problems, confusion and inconsistency. If we inquire in the general population, ignorance of what the body is, how it is constituted and how it works - i.e., of anatomy, histology, embryology and neurology and physiology -- is appalling. Common and wide spread beliefs and superstitions as to the causation of disease (and kinds of "cures") astonish us as we hear them proposed in all seriousness. Nor does the uneducated have a monopoly on ignorance and wrong point of view in such matters. Truly it is brought home to us many times that a little learning is a dangerous thing. These people can vote, legislate and propagandize dangerous half-truths which someone has said are worse than deliberate lies.

If the hypothetical "average" man (who never exists) is obscure on fundamental matters of astronomy, economics, anatomy, bacteriology, etc., what of his knowledge, insight and skill in the mental realm?

Many a college junior when asked "What is psychology?" answers glibly "the science of the behavior of living things." If you then ask "What is behavior?" and demand clear, precise and verifiable statements you are generally rewarded by a look of astonishment and a strong preference not to push the matter any further. And college juniors represent about the top 3% of our population so far as affairs of the intellect go. They are the embryo policy makers

and pace setters of the next decade or two.

It is quite evident that here we find the importance of viewpoint doubly emphasized. To try to present to a "layman," untrained and wrongly biased, a resume of recent work on such problems as space perception, for example, is almost a hopeless undertaking. This is particularly true when the bias contains a set of easy, logical (to him) "explanations" gathered from indiscriminate sources. It is a pioneering job to divest the soil of these often firmly rooted weeds in order to prepare it for the tested seed of fruitful science.

Later we shall return to this question of point of view in psychology. It touches optometry the same as everything else. I daresay that after very brief search I could find you numerous persons convinced that eyes are literally the windows of the soul; and still more numerous others who think of vision as a simple mechanical process, a nickel-in-the-slot sort of thing. Pictures on the retinae and the same pictures somehow projected in the brain. If you casually mention the facts, shown by recent research, that in uniform illumination as a pattern of light falls upon the retinae some of the photosensive cells only fire upon the cessation of or sufficient reduction in the intensity of the light. Others fire, first in a burst and then settle to a slower frequency, throughout the duration of the excitation. This latter type must give us the basis of all differences of photometric intensities and therefore play a primary role in the resolving power of the eye, form discrimination, etc. Only 20% of the photosensitive cells are discharging during continuous stimulation, and the frequency of the afferent volleys of ions vary with changes in intensity of illumination from about 5 to 150 to 200 per second in the human. Add to this the fact that the retinae themselves are a region of transformation, so that it is impossible to regard the thing seen out there as a direct projection of the light pattern.

The response to this, and more of similar facts, is usually again a look of incredulity and astonishment, and often a quick shift of the conversation to safer ground.

Science is not just a method of massing and accumulating "facts," which an Arabian scholar once called "the idlest of superstitions" but it is an orderly and systematic arrangement of the pieces so that the puzzle picture is complete, unitary and has meaning. This is always the most difficult part of scientific work. James one time called it "thinking things together," not out of whole cloth but produced by rigorous sifting and checking. Without the guiding help of a proper and appropriate point of view this constructive and creative step is made difficult or impossible.

The expansion of basic concepts has completely transformed physics in our own generation, and the results are discoveries of the greatest importance to the present and future. A hasty examination of the history of the inductive sciences convinces one of the primary importance of viewpoint. We must profit by these hard won lessons of the past if we are to travel far on the road to understanding in our short lives For time is fleeting....and there are no short cuts or royal roads. One of the greatest advancements lies in the fact that all the various divisions of science are beginning to speak the same language and therefore to understand each other. Field dynamics, which has done so much for physics and chemistry, is beginning to do the same things in biology and psychology. If atomism would not <u>do</u> there, we may rightfully seek out its inherent limitations as it applies to our own work and interests. A scientist should make every effort to keep open minded and be ready to change his ways of thinking, his concepts of problems and methods as experience and broader, clearer views grow and develop. He must shun bias and cultivate a readiness to abide by the verdict of carefully made experiments, letting the chips fall where they may.

It is easy to cite instances of the incapacity of a man trained in one field to appreciate or to form valid judgments about the subject matter and methods of another. It is, too, the failure to see the forest for the trees in ones own sphere. One of the most dismal lectures I ever listened to was delivered by a world famous physicist talking, as would the rankest amateur, about the workings of the mind. One should earn the right to have and voice opinions. Serious attention to either approbation or criticism should not be given until we have calibrated the reporter. We must first ask "Is the judgment competent?" And the judgment can only be competent if it is backed

by the requisite training, insight, experience and skill. These things are never given, but must be won.

One can fully expect that there are those who will always regard the field of phenomenal vision, or seeing, as something curious, perhaps of passing interest, but not for them. They will prefer to stick to the pointer readings of their instruments, to 0.1 or even 0.01 diopter. The fact that the "rules" often do not hold does not trouble them. Can it be that optometry has waiting for it just around the corner a vast, new and explored field? That in the years to come advances along these lines will completely transform instruments, techniques, and even the legal and social status of your profession?

It would be possible to detail here practical illustrations of dramatic success of a number of your colleagues in the treatment of non-refractive cases of poor vision. When, for example, a serious squint is corrected permanently, without either lenses or surgery, not once but in two thousand cases, by a comparatively simple technique, and when this technique can be taught to others so that they too can produce the same result, even the most skeptical must fact the facts. We do not know but a few of the great possibilities in this field.

Points of view are bound to differ; to be in the continual process of making, unmaking and remaking. It is healthy for any field to have the constant challenges, checks and proofs resulting from these differences of attitude and viewpoint.

It would take a sizeable book to set forth the whole theoretical framework in which the many problems relating to seeing are to be handled. Naturally all would not agree with the postulates thus set up. But no other satisfactory method has been found other than to try out tentative ones and to depend upon the results of careful investigation to verify them or to start over and produce a better set.

In approaching the study of vision and visual processes we must come to a decision as to whether we shall regard and study them as molar or as molecular processes.

If we take the molecular point of view we shall try to analyze the processes into their elementary constitutents, breaking them down into their simplest forms and functions. We shall study seeing by learning all we can about light, photochemistry, neurology and histology of the receptors, nervous and non-nervous conduction, etc.

Critics of this procedure maintain that we can never approach a true description of seeing by this path; that such an analysis destroys the very thing we are seeking; that once we have described and measured the "elements" we have contributed little or nothing to the proper understanding and functional properties of the whole, no matter how detailed and precise our knowledge of the separate independent parts.

The molar attack is the other way round. It holds that the whole is the primary reality. Wholes are not made up of independent parts, because parts are only independent because we make them so by an arbitrary process of analysis and classification. When we dismember a complex and isolate a part, we disrupt oft times the delicately balanced interrelations and create artifact and unreality. A frog's gastrocnemius muscle in a moist chamber, electrically stimulated will shorten and record its track on a kymograph. It is insisted that the same muscle under the intact skin and fascia, supplied with blood and lymph, and the natural nerve supply, behaves in quite a different fashion especially if the frog must leap for his life, or outdo a competitor in the courtship arts. "Plants build cells, not cells plants" said a pioneer botanist many years ago. This is the cell theory vs. the organismic theory in biology. Which road shall we take?

We often hear that such questions are academic and impractical. It is said that one can just as well straddle or disregard the issue -- thus take the so-called eclectic position. This kind of thing leads only to muddled thinking and to inadequate, uncontrolled and inconclusive experimentation. A little consideration will show that both the kinds of problems and methods and hence the value of the end products inhere in this all important first step - the clearest formulation of the basic plan or viewpoint we can achieve. When we do this we save ourselves from much wasted effort, from many fallacies. Fake "cures," devices and principles cannot thrive in the light of honest and competent search for the truth. False beliefs, palmistry and phrenology and selecting assis-

tants on the basis of skin texture, coloring, and the like are given their just due promptly. Careful work has shown that such a thing as courage, invaluable in war, can not be predicted from <u>any</u> physical characteristic. So it is with honesty, intelligence of any other form of behavior. Consult the work of the Galton laboratory and the files of Biometrika, or the Sigma Xi lectures by Harris, Jackson, Paterson and Scammon at the university of Minnesota in 1930, if you wish the evidence.

In subsequent papers we will talk about things which may be more interesting, but certainly not more important. The taller the building the deeper and firmer must be the foundation.

Take stock of your viewpoint. It will pay good dividends in professional growth -- and satisfaction.

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by Samuel Renshaw, M. A., Ph. D.
Ohio State University

Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

SOME CONSIDERATIONS REGARDING THE VISUAL STIMULUS

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In the two preceding papers we have given brief consideration to the distinctive problem and subject matter of Experimental Psychology and to the importance of point of view. This third paper will continue the lines of argument developed in our discussion of the importance of viewpoint.

Early in the history of psychology many men decided after looking at the accomplishments of other older divisions of natural science that the proper and profitable procedure in the attack on psychological problems was to utilize, insofar as possible, the tools and methods of the other sciences. The result was the development of the principles of sensation, simple image, and simple feeling as the elementary mental processes which in varied combinations could be synthesized into the complex processes.

Of course, in order to accomplish this synthesis, it became necessary to create another kind of function which served as the mode of combination of the assumed separate elements. This was the principle of association. The postulation of these basic elements, and of the fundamental manner of combining the elements into larger aggregates, formed the basis of the principal experimental and theoretical work for almost a half century. But very early it became evident to a number of scholars that the atomistic assumptions postulated in the foregoing were wrong. By a process of analysis they could get things reduced to these hypothetical units, but the efforts to start with the units and to produce, by the method of the synthetic experiment, combinations to produce other complex processes met almost invariably with failure. Along with the rapid growth of knowledge, particularly in the biological field, there appeared a growing dissatisfaction with this kind of a formulation. It became clear that in order to do effective work in psychology, it was necessary for psychologists to abandon the hope of producing the same fruitful results with the methods, concepts and devices borrowed from the other divisions of science. Psychology had to devise its own special apparatus and methods, suited to its own particular requirements.

The number of those who objected to the sensation and association doctrines steadily increased until in quite recent years it is fair to say that both of these principles have come to represent historical episodes in the progressive evolution of psychology as a science. We shall hope to show in subsequent papers abundant evidence to illustrate the fact that many of the processes which we designate as learning, perceiving, remembering, and the like, are incapable of description in terms of these obsolete doctrines. Try as one will it is next to impossible, except under a very special set of conditions, to set up an experiment in which the "laws" of association can be demonstrated. It is undoubtedly true that associationism held back progress for many years because it furnished an easy logical answer to many difficult problems. But here again, closer inquiry revealed that the easy, common-sense answers furnished by logic were not capable of substantiation under the rigorous conditions of laboratory experimentation.

Out of such considerations developed what has been called the stimulus-response psychology. This approach finally reached such a climax that we were told that if we knew the response any organism was making we could predict the nature and magnitude of the stimulus which elicited that response. Conversely, the prediction and control of behavior became the problem of determining the degree of covariance between stimulation and response.

Such considerations came into sharp conflict with certain well-known principles relating to the properties of all protoplasmic structures. It was pointed out, for instance, by Professor R. S. Lillie that no constant relationship exists, or can exist, between the exciting agent or stimulus either qualitatively or quantitatively and

any property of the resulting reactions in a protoplasmic mechanism. Critical attempts to stipulate and define stimulus soon revealed that such a concept left much to be desired as a scientific formulation. This was because it was shown to be practically impossible to localize "the stimulus" in space and time. The mere fact of memory, added to that of set, predisposition, desire, purpose, intention, instruction, drive, motive, anticipation, and the reactor s perception of his total relation to the stimulus situation practically robbed the term of any specificity which it had or could possess. If one were to try to precisely isolate "the stimulus" even under simple conditions the effort usually terminated unsuccessfully.

The way out of this difficulty has been to retain the term "stimulus", using it to loosely designate the entire aggregate of sensory and motor events which precede any observable and measurable instance of behavior. We think of the reactions of an organism to its changing environs as a complex system of efforts to restore the best possible equilibrium when changes in the surrounds have upset the previously existing adjustment of the organism to these surrounds. An organism thus must be conceived, from birth to death, as a system in continual reaction, the stream of which is now interrupted and turned in a different direction by other series of energy manifestations which introduce the necessity for some sort of behavioral readjustment. We react with and never to the types of changes in our environs which we classify as stimuli. These are simply changes in the energy relations of the organism and its surrounds. They serve as the trigger mechanisms for releasing energy stored at strategic places in the body. As Verworn pointed out many years ago, all that stimulation can do is to heighten the rate of oxidation of a process already going on. A stimulus is a signal or a cue, and part of it always is supplied by the contractile and secretory apparatus involved in the resulting adjustory movement.

One of the most devastating criticisms which has ever been aimed at the sensation doctrine in the demonstration of the fact that the stimulus lies inside and not outside the act itself. Another potent reason why we should look with great skepticism at this doctrine is the fact that if the motor mechanisms of the body are interfered with or if they are prohibited from consummating their normal adjustory functions then sensory stimulation fails to give rise to conscious experience.

A third deficiency of the doctrine lies in the fact of the unity of the senses. It is practically impossible to dissociate vision, hearing, kinaesthesis, smell, taste and the organics. The whole trend in the evolution of the central nervous system has been to produce a mechanism in which these functions are rendered unitary rather than separate and distinct. Vision, for example, is always set in a framework of helpful, surrounding and assisting functions which come from posture, from hearing, from the tactual and motor sources of the reagent.

We must take the point of view that a seeing organism utilizes its eyes as distance-receptors. The fact that we can see an approaching train or automobile and can prepare for ourselves in advance a position of safety with respect to the on-coming object contains within it a fact of the greatest psychological and biological importance. The evolution of distance-receptors made possible the making of delayed responses. That is to say, we can be stimulated by a command in the present moment and after deliberation we can respond at some convenient or appropriate future time. The possession of this mechanism furnishes the groundwork for the acquisition of language, and for the development of the complex functions of perceiving and remembering which lie at the heart of man s rise to his position of supremacy in the organic world.

THE RESPONSE OF THE EYE TO LIGHT STIMULUS

The effective stimulus for vision is the band of radiant energy which ranges in wave lengths from about 390 mu mu to about 760 mu mu. The unit of measurement, the millimicron, designated mu mu, is one-millionth of a millimeter. Sometimes for more precise description the Angstrom unit is used. Each Angstrom unit is one-tenth of a millimicron in wave length. The band of visible lights begins with wave lengths at the red end of the spectrum in the neighborhood of 700 mu mu and extends to the shorter wave lengths at the violet end and visibly terminates at about 400 mu mu. This range represents only a very tiny fraction of the total spectrum of radiant energy. Newton demonstrated that white light passed through a prism breaks down into its spectral components and that

once this is done, if the spectral band is refocused to a point by a concave mirror, the separate wave lengths will again produce white light.

It is customary to measure light in three kinds of units. The first of these is the erg. The energy received by a unit area of a surface is caused to fall upon a thermopile. This device measures the mechanical equivalent of heat produced by the transformation of light energy into heat energy. The method is applicable to the ultra-violet and infra-red as well as to the visible spectrum and is independent of the judgment of the observer. Another variation of this same method is to use some type of photronic electrocell or photoelectric cell. This instrument consists of a metal plate upon which is deposited a uniform layer of the salts of certain other metals, such as selenium. When light strikes the cell it sets up an electrical potential which then can be measured by a sufficiently sensitive detecting device such as a galvanometer or microammeter.

A second kind of unit and one widely used is the footcandle or metercandle. A candlepower is defined as the intensity of a source of light equal to that produced by the flame of a spermaceti candle weighing 0.167 pounds and burning at the rate of 120 grains per hour. Let us regard this source as a point of light and assume that the light energy is radiated equally in all directions. If the source is regarded as the center of a sphere of radius <u>r</u>, then the total quantity of light or luminous flux is distributed over the surface of the sphere, whose area is $4\pi r^2$. It is arbitrarily agreed that a source of one candlepower gives rise to 4π units of light, each known as a <u>lumen</u>. Therefore, any portion of the surface of the sphere that has an area of r^2 receives one lumen of light. The illumination is the amount of radiant energy incident upon a surface of unit area. Thus we speak of one lumen per square meter, known as the <u>lux</u>; one lumen per square centimeter known as the <u>phot</u>; or one lumen per square foot. It is clear that illumination will depend upon the intensity of the luminous source and upon the distance of the illuminated surface from this source. From a given source the luminous flux that reaches an area of a square foot, say, on the surface of a sphere with a radius of one foot, is the same total quantity as that reaching an area of four square feet on the surface of a sphere whose radius is two feet. Furthermore, at a radius of two feet the illumination produced on one square foot of area by the same source is one-fourth that produced at a radius of one foot. These facts are generalized in the form of the inverse square law:

$$L = K \frac{I}{D^2}$$

where the illumination L is directly proportional to the intensity of the source, I, and inversely proportional to the distance between surface and source.

If the surface is one foot from a source of one standard candlepower the surface is said to have an illumination of one footcandle. If the distance is one meter, it has an illumination of one metercandle. Under these conditions the constant K in the above equation becomes unity since I equals one candle, D equals one foot and L equals one footcandle. The metercandle is equal to the <u>lux</u>. The truth of this assertion rests on the fact that the lumen is defined as the luminous flux per unit solid angle. A solid angle is a cone or pyramid whose apex is the center of a sphere and whose base is that portion of the surface of the sphere subtended by the size of the cone or pyramid. A unit solid angle is such a pyramid or cone whose slant height is equal to the radius of the surface R and whose base has an area of R square.

The reflectance of a surface is its property to emit a portion of the luminous flux incident upon it. It is measured in terms of the ratio of the reflected light to the total incident light. This measure is known as the reflection factor or coefficient of reflection.

Differences in reflectance are in part responsible for the different apparent illuminations of various surfaces. An appropriate unit for this measure of brightness is the <u>apparent footcandle</u>. This unit is simply the product of the illumination, that is, incident light, by the reflection factor. A more satisfactory measure of brightness, however, is expressed as luminous flux per unit area. A better way is to express brightness as candles per unit area, or still better, as lumens per unit area.

A <u>lambert</u> is equal to a flux of one lumen emitted by one square centimeter of per-

fectly diffusing emissive surface. A millilambert is equal to .001 lambert. The units of illumination and of brightness can readily be converted. Thus, footcandles, metercandles, apparent footcandles, candles per square meter and millilamberts may be equated if the reflection factor is known.

A third type of unit is the psychological or brightness unit. Brightness or brilliance as distinguished from radiant energy is in the final analysis a property of certain psychological functions. We would not expect to be able to specify the brilliance of a visual object merely in terms of the intensity of luminous flux, reflection factors and distance from the source. In addition we would expect that contrast of either the simultaneous or the successive order, degree of adaptation--both photopic and scotopic, the size, form and texture of the visual object as well as its mode of occurrence (that is, whether surface, film, bulk, or lustre), the size of the pupillary opening and the set or attitude of the subject would severally play their respective parts. In connection with pupillary size, Troland has proposed a unit which is proportional to retinal illumination and which depends upon pupillary size. It is the <u>photon</u> and is defined as the product of candles per square meter and pupillary size in square millimeters.

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

 Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

SOME CONSIDERATIONS REGARDING THE VISUAL STIMULUS
PART II

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The amount of light reaching the retina will vary directly with the area of the pupil. Pupillary size is proportional to the light intensity at the eye opening. The higher the intensity of illumination the smaller will be the pupillary opening. When we pass from bright sunlight into a dimly lighted room we see nothing until we become dark-adapted. The degree of dark adaptation is customarily measured by the intensity of the threshold stimulus, i.e., the amount of light which can just be discriminated from the ground upon which the test patch is viewed. It has been found that after an hour in the dark the threshold intensity for a normal eye diminished to approximately one-hundred-thousandth of its value in moderate illumination.

In the dark-adapted eye the diameter of the pupil will be about 8 mm. At 0.01 millilambert field illumination the size becomes about 6.7 mm; at 0.6 millilambert the pupil is 5.3 mm; at 6.3 ml. it is 4.1 mm; at 126 ml. it is 2.6 mm. At 355 ml. it was found to be 2.3 mm. and at 2000 ml. the pupil reached its minimum size of 2.0 mm. These measurements were obtained with both eyes open. If a single eye is stimulated, the other being masked or kept closed, the pupil sizes are slightly larger. The light admitted to the retina varies as the square of the pupil diameter. Between the extremes of 2 mm and 8 mm therefore, about 16 times as much light <u>can</u> reach the retina, if the eye is dark-adapted, than if it is in strong illumination. But the dark-adapted eye is so far more sensitive to light than the daylight eye that the opening of the pupil can account for only a slight fraction of the difference, which must be a change in the chemical and neural responses of the retina to light.

This change in sensitivity does not take place uniformly over the retina. Von Kries studied this problem by having his observers fixate a point source. At the same time a white surface whose brightness could be varied was presented to the eye at various distances eccentric to the line of sight. When the surface was illuminated by a bluish-white light and the foveal sensitivity was taken as unity, it was found that sensitivity increases quite rapidly, both nasalward and temporalward, from about 1.5° from the fovea and reaches a maximum at about 4.5°.

Reeves photographed the eye with a motion picture camera to measure the rate of the dilation and constriction of the pupil in the change from light to dark adaptation and vice versa. He found that the opening of the pupil to a maximum diameter in dark adaptation required as many minutes as it required seconds to constrict to a minimum in bright light.*

From the faintest to the maximally tolerable brightness the range of light intensities is very great. The threshold for brightness in the dark-adapted central field is about 0.275 microwatt per sq. M. of illuminated surface. A microwatt is a millionth of a watt. One watt represents the expenditure of 10 million ergs on energy per second. An erg is approximately the energy required to raise a gram weight .001 cm. against gravity. On the periphery of the retina the threshold is only about one-thousandth of the value for the macula. The above figures represent large stimuli. Very small point sources, like stars, show even more strikingly the sensitivity of the

* (The use of Eastman or Afga infra-red film and of appropriate strength light sources through Wratten No. 87 filters makes photography by either "still" or motion picture cameras in complete darkness (to the eye) virtually as simple as in daylight illumination with panchromatic or ordinary emulsions).

retina. To quote Boring, "The power of a faint star, visible in peripheral vision, is about 10^{-8} microwatt (100 million millionths of a watt; one thousand millionths of an erg per second). Such a star would have to shine on the retina for forty years to deliver an erg of energy to it. If it can be perceived in a fifth of a second, as seems probable, then the retina is some 30,000 times as sensitive as the most sensitive radiometer which the physicists use for measuring radiant energy."

Thus we see that the intensive range of light which the eye can discriminate from the faintest to the brightest intensity represents an enormous range. However, if we take a white of the order of brightness of a sheet of white bond paper reflecting the north sky at noon and a black of the approximate coefficient of reflectance equal to printer's ink, we may ask how many just perceptible steps of brightness can be discovered in this achromatic series which will vary from white through neutral gray to black. This experiment has been made a number of times by different investigators. The method used has conventionally been the method of minimal change. If we start with the standard white and then make a comparison surface just perceptibly darker than the standard, measure the difference and then take this new value as a standard and repeat the procedure, we can thus determine the number of steps, sometimes called JND units or just-noticeably-different steps within the brightness range of black to white. It is obvious that the number of such steps will depend upon the intensity of illumination, upon the state of adaptation of the eye, and certain other factors which need not be mentioned here. In contrast to the enormous range of physical brightness, the number of JND steps from white to black under 20 apparent foot-candles varies with different observers from about 160 to 350 with the average at approximately 210. Thus the eye can make approximately two hundred discriminations of brightness of a surface, namely, white paper reflecting the north dky having a coefficient of reflectance of about .82, to black having a coefficient of about .05. Within these limits there are about two hundred discriminable shades of blacks and grays and whites.

Perhaps the earliest experiment of this kind was made by Bouguer in Paris in 1760. In 1858 Fechner noticed that the ratio $\frac{\Delta I}{I}$ was approximately constant regardless of whether I, that is intensity, was large or small. This value has been found by various investigators to be approximately 1%. In other words, 1% of any intensity of illumination except the very highest or very lowest added to that illumination will make it just perceptibly brighter. This is really Weber's law and was announced in 1834. It says merely that the ratio $\frac{\Delta I}{I}$ is a constant. Fechner expanded the concept by assuming that all discriminable increments of sensation were equal; and by assuming these increments to be infinitesimal and integrating, he obtained the equation

$$S=k \log (I/I_o).$$

This is the formula for Fechner's law which became the basis for a tremendous amount of subsequent work on the problem of the measurement of intensity.

Using crude telescopes not much better than the average opera glass, the early astronomers classified the fixed stars into groups of six magnitudes, the brightest being the first and the faintest visible star the sixth magnitude. To the eye each magnitude is just noticeably brighter than the magnitude preceding. Thus, the six magnitudes represent equal sense distances. These relations can be expressed as $M=C-k \log I$ where M is the magnitude of the star, I the quantity of light reaching the eye from it, and k is a constant which has the approximate value of 2.5. When the magnitude increased one step log I increased by 0.4 and the light reaching the eye from the star increased 2.5 times. This follows from Fechner's law. The light had to increase 2.5 times instead of 1.01 times in the case of stars because stars are point sources instead of extended surfaces. Since these early times, and using greatly improved instruments of precision, the value $\frac{\Delta I}{I}$ has been determined by several investigators with great accuracy, and although separated by a half-century, with almost perfect agreement, so that in the present day light intensity relations can be specified with considerable assurance for persons possessing normal vision.

The pattern of precision work was really set by the investigation of Konig and Brodhun. Observations were made on small differences of intensity in terms of an arbitrary unit which ranged from .002 to one million of these units. Observations were

made not only for white light but also for wave lengths 670, 605, 575, 505, 470, and 430 mu mu Konig's intensity unit has subsequently been found to equal 0.2 millilambert. More recently these observations were repeated by Blanchard, Ives, Priest, Houston, Hecht, and others. An interesting development arose from a comparison of the curves obtained for white light and the various colored lights. Out of this work there was developed the observation first made by the great Austrian Physiologist Purkinje, which is called the Purkinje effect, namely, that in daylight adaptation the brightest part of the visible spectrum lies in the vicinity of wave length 556 mu mu and in scotopic or twilight vision the point of maximal brightness shifts from this position (in the yellow) to 511 mu mu, which is in the region we call green. It was noticed that if a red light and a blue light were being equated for brightness, using a simple instrument like a Bunsen Grease Spot Photometer, and the observer equated them with his eye close up, that is, from about two feet distance, and then repeated the observation from about twenty feet, the obtained values were not the same. This was due to the fact that at the greater distance the eye became more dark-adapted and with it came a greater change in the relative brightness of the blue and red lights. The following figure illustrates the visibility curves of human vision for both the scotopic and photopic adaptations. The photopic curve represents the light-adapted eye, the scotopic one represents the dark-adapted eye.

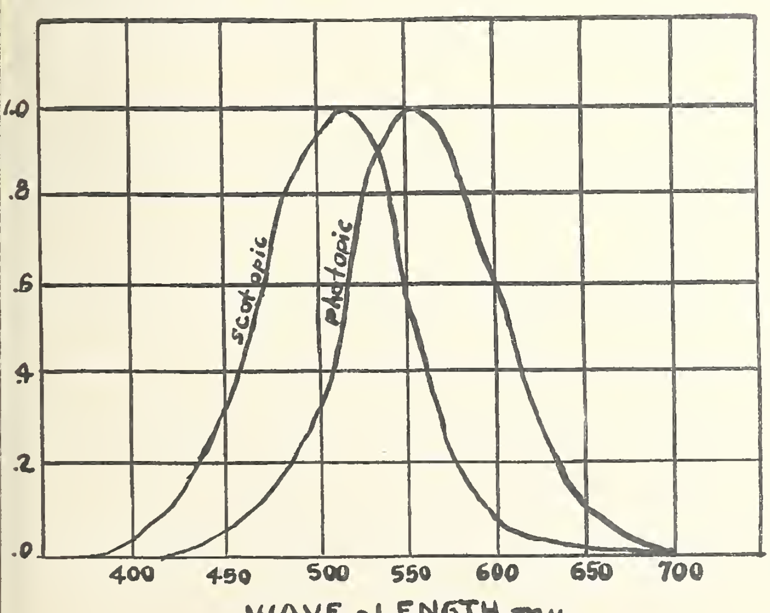

Fig. 1

These two curves should be studied very carefully because they are of great importance. The visibility scale representing the ordinates is determined by setting the spectral light of highest brightness at unity. For the daylight eye wave length 554-556 mu mu represents this point The spectral hues of visible light are all contained within the range from about 400 to 700 mu mu. The red band extends from about 647 to 760; orange 588 to 647; yellow 550 to 588; green 492 to 550; blue 433 to 492; and violet 390 to 433. Within this range Jones found that 128 just perceptibly different hues could be discriminated. Thus it will be noted that the number of hues in the visible spectrum is considerably smaller than the number of achromatic steps within the range of light intensities. Thus referring to figure 1, in photopic vision a bluish light of wave length 450 would have only about half the visibility of a red light of wave length 650. From the curve it can be ascertained immediately that when the eye becomes dark-adapted, yellow at wave length 550 is reduced from a visibility of 1.0 to approximately 0.5.

From studies on the intensity relationships of lights of various wave lengths, the duplicity theory of Von Kries was produced According to this theory vision at high intensities is carried on by the functioning of the cones, and at low intensities when the spectrum appears colorless, by the rods Rods and cones were held to have separate and independent visual mechanisms; the rods, having a lower threshold than the cones, come into action earlier when intensity is raised from zero. Within a certain range both mechanisms contribute their parts to sensation but at high intensities the cones dominate the scene and render it more or less immaterial as to whether the rods are active or not. There is considerable evidence both for and against the duplicity theory which has gained for itself almost universal acceptance for the simple reason that no other more satisfactory theory has been proposed. Recently Parsons, and Lythoge and Tansley have shown that under certain circumstances rods may act like cones and that certainly cones seem to be dependent upon chemical excitors produced in the rods, for without the assistance of this substance the cones fail to perform their customary functions. The eye is a photometric instrument of great precision. When proper understanding of its structure function properties are attained, greater care of such a valuable instrument will be taken.

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

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OPTOMETRIC EXTENSION PROGRAM

SEEING AS A HABIT

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In relation to our previous discussions of the problem of intensity it should be understood clearly that our sense organs are essentially compensatory devices; and that they do not serve to collect and transmit to the central nervous system and to the effectors accurate indices of energy changes in the external environment. The nervous system has evolved as a device for propagating weak signals. These signals never stand in a direct one-to-one ratio to the intensive series of physical events which produce them. When a pattern of illumination is collected by the lens and brought to more or less sharp focus at the retinal surface it produces a very complex series of electro-chemical changes which in turn are picked up by the rods and cones and these start discharging afferent volleys in the bundles of fibers which comprise the optic nerve. (Cf. Page 2, Vol. 1, No. 2)

What we mean when we assert that the eye is a compensatory device can be illustrated by the following experiment. I place a piece of black velvet upon the window sill and let the north noon-day light be reflected from it. With the aid of an instrument, such as a Macbeth Illuminometer, I measure the brightness of the black velvet surface in apparent-footcandles, record this value and immediately set up a mixture of black and white on a Maxwell disc rotator which will give me the same coefficient of reflection. In this first step of our experiment I have arranged conditions so that the brightness of the light reflected from the rotating black and white sectored disc is the same as that of the velvet reflecting the noon-day north sky. For the second part of the experiment I go out into the yard where there is a covering of freshly fallen snow in the light of the full moon. I set up my illuminometer and take a measure of the light reflected from the white snow in the full moon light. I record these values in apparent-footcandles, return to the laboratory and upon a second Maxwell disc rotator I adjust the proportions of black and white discs so that its coefficient of reflection gives me the identical value of the white snow in the moonlight. If now I call in a student and ask him to look at the pair of spinning discs side by side, each a duplicate of black velvet and white snow, and ask him to describe what he sees, his statement will be as follows: "On the left I see a circular disc which is white" (the duplicate of the reflectance from the black velvet), "and to the right I see another disc which is black" (our match of the white snow in the moonlight). If now I take this same student out into the moonlight and ask him to look at the white snow and tell me what he sees, he will invariably report that the snow is very white and if I show him the velvet in the sunlight he will report that the velvet is very black compared, for instance, to the whiteness of white paper. The student has perfectly normal eyes and his discriminations of brightness are at least as good as those of the average student. The phenomenon which he has exhibited teaches us that what he sees in the way of the brilliance of the test surfaces is in no wise revealed by the absolute description of the relative brightness of these patches. In spite of the remarkable sensitivity of the eye to small differences in brightness, gross errors are made in comparing relative brightness for the reason that interpretations of the stimulus patterns impressed on his retinas do not follow a one-to-one correspondence between the characteristics of the stimulus and of the resulting discriminations. This is but one of numerous instances which show that we never see exactly what is presented to the eyes. If we did, the world of visual experience would instantly become a hopeless chaos. Paradoxically this erroneous reporting by the sense organs is the beneficial phase of the functioning which makes them useful to us.

Color, shape, position and movement are subject to the same transformations in

seeing as we have observed in the foregoing illustration. The retina serves among other things to suppress certain portions of the intensive scale of impressions brought to it and also serves to enhance other portions. If we could cut a cross-section of the thousands of fibers comprising the optic bundle and at any instant carefully describe the composite pattern of what the retina is forwarding to the mid-brain, corpus striatum and cerebral cortex, we should find that the energy density distribution in the optic bundle bears no correspondence to the size, shape, position, intensity or hue of the physical visual pattern <u>out there</u> which gives rise to it. If we were to explore the surface of the brain with a small pair of platinum electrodes and amplify the electrical disturbances throughout the cuneous regions of both hemispheres, what scientists have found who have made these experiments is a pattern of diffusion of energy. From it we could not identify the shape, size, color, position or distance of the stimulus pattern. Between the object <u>out there</u> at which we were looking and our discrimination and recognition of it, there lies a most complex series of phenomena.

It is necessary also for us to keep in mind the fact of the unity of the senses. By this I mean that when the impulses from the eyes reach the mid-brain they are immediately correlated with other incoming impulses from the skin, the muscles, the articular surfaces of the joints and from the ears. By the time this aggregate reaches the brain cortex it is inconceivable how anyone could separate the visual components from those originating in other sense modalities. Unless we are willing to recognize the fact that the act of seeing is contingent upon and completed by the series of adjustory motor events and the back stroke from them which, referred back to the central nervous system, completes the organic circuit, we have no other way of enabling us to conceive clearly how any sensory discrimination is at all possible.

It has been repeatedly pointed out, for example, that in the absence of continuous fine tremor movements of the eyes marginal contrast would be reduced to a minimum or completely eliminated. In such a case it is difficulty to see how the retinal surface would possess the degree of resolving power necessary for clear vision. Numerous illustrations can be cited to show that an individual may have the eyes stimulated with light patterns and although the eyes are wide open and the visual mechanism intact, no seeing whatever takes place.

Jacobson showed in his progressive relaxation experiments that after his subjects had become sufficiently trained so that they had complete voluntary control of the extrinsic and intrinsic muscles of the eye as well as of the speech mechanism, such subjects could completely relax these muscles and when this state was attained vision and even visual imagery completely ceased. In the hypnotic trance complete control can be exercised to the extent that only specified classes of objects in the visual field can be seen although others, completely suppressed, are optically present.

The basic function of our sense organs is to instigate movements by approximation and correction of an adjustory or adaptive character. The terminus of any visual act is motor. What we see becomes largely defined in terms of what we do about the things we look at or what they do to us. It is indeed significant to consider the fact that vision and visual discriminative capacity varies in the animal series quite closely with the capacity of the animal for locomotion. Those animals who move about in space most rapidly such as the birds, must have and do have the sharper and more rapid visual discrimination. It follows from such considerations that in proportion as human life becomes more limited in its motor aspects, there is a corresponding decline in comfortable, clear vision with adequate reservations for rapid accommodatory adjustments.

Every artist realizes the fact that field dynamics play a tremendously important role in his activities. To illustrate, suppose I place before you a piece of drawing paper of conventional letter size; I hand you a crayon or a pencil and tell you to make a dot five millimeters in diameter any place you desire on this sheet. If now I ask you to make a second dot any place else upon this sheet, it immediately becomes apparent that the presence of the second dot <u>does something</u> to the appear-

ance of the sheet when it contained only the first dot. It also is evident that the change occasioned by the addition of the second dot is a different kind of change than that produced by the placing of the first dot upon the blank page. The space between the two dots is visually not the same as the remainder of the area of the page. Two dots are members of a binary pair and as such mutually interact with each other. Thus we have the beginning of a complex structure in the visual field.

When we look out of the window upon the landscape the relative sizes, positions, shapes and colors of the several objects comprising the scene, each is altered by reason of its presence in relation to the other components. Whether the aggregate constitutes a tightly closed system and maintains itself as a "good" composition largely depends, as everyone knows, upon the relative arrangement of these components. Set one tree in a different position and what was previously a pleasing and harmonious picture becomes now only a drab, snapshot record. Not only is it impossible to predict this "goodness" of total form from any characteristic of the visual pattern itself but is it equally impossible to predict that in one case the perception and memory of the two scenes will differ radically from the other.

Just as we have previously pointed out that we never see exactly what is <u>out there</u>, so we shall hope to show in subsequent papers that neither do we remember what we have seen Seeing, perceiving, and remembering, therefore constitute a continuously variable series of events, dynamic in character, and to a large extent dependent upon very definite psychological aspects of the act of seeing. It is perhaps just as important to know something about the frames of reference by means of which we interpret our visual impressions as it is to know the optical constants of the eye itself, or the mechanisms, neurological and anatomical, which lie behind the retina. It is my contention that these former things will become increasingly more and more important in the practice of optometry as time goes on and as we come to understand them more clearly and therefore gain the capacity to control them.

Perceiving always involves tentative and anticipatory movements. These are partly postural and partly executant. As the pattern of perceiving becomes more completely organized the series of implicit and explicit motor processes are continued and extended. The "search for meaning" when we examine any new unknown is a search, by the method of approximation and correction, for some expedient and consummatory motor adjustment.

Finally two things seem for force themselves upon us as we think of these things. Seeing, like any other skill is a habit and is therefore susceptible to practice or training effects. This opens the way for orthoptic practices, in proportion as the principles are known. Secondly, the analytical examination which leads to prescription or treatment or what-not should be taken in conjunction with full etiology. The genesis of the visual reference frames possibly lies in total organization of the personal habit system of the patient, all of which argues for full case histories and complete records taken by the diagnostician himself.

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

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OPTOMETRIC EXTENSION PROGRAM

SEEING AS VISUAL PERCEPTION

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A fact of great importance to all workers with visual problems is the naive assumption, widely held, that the seeing of a landscape, a face, or any complex visual pattern, is a simple process of copying or imaging the sensory pattern in the brain. Even among certain scholars conventional perceptual theory holds that the properties of perceptual experience are determined by the properties of sensory excitations and the consequent processes in the brain.

There are numerous reasons why such a view cannot be accepted. For example, Therman (1938) has called attention to the fact that "the retina can be decidedly active when the optic nerve discharge is virtually if not actually absent." Further, he has pointed out that "contours could never be seen if the optico-physiological pattern of activity had to copy the stimulus." Also that "contours are seen . . . under some conditions where they do not physically exist in the stimulus, and fail to appear where they would be expected." Every psychologist who has studied the problem soon meets with the fact of perceptual filling; that is, we always see more in the stimulus than is actually present. Perhaps it would be better to say that we always see both more and less than that which is represented in the physical stimulus pattern. This is another way of saying that the act of seeing is an act of bringing to the situation a variegated pattern of frames of reference, some of them built up out of previous experiences and some of them due to the complex, suppressing and enhancing influences which arise from the interplay of forces in the visual field.

In the paper preceding this one a simple illustration was used in which an artist was described as asking a student to make a single black dot any place on the surface of a clean 5 x 8 card. Suppose the dot is made in the geometric center of the card. The student is then asked to make a second dot upon this card. The mere presence of the second dot in the visual field, which also contains the first dot, adds a tremendous complication to the events happening in the optical sector, which includes eye, brain, and the whole muscular apparatus of the body. Let us examine this simple case more closely, because from it we shall discover the ground-work of the modern view of perception which stands diametrically opposed to the conventional view briefly stated at the beginning of this paper. This theory holds that perceptual phenomena have a dynamic or motor basis. What we perceive depends not upon the mere reception of visual impressions at the retina, but upon action patterns. It is impossible to look at the white card referred to above, which contains first one dot and then two, without giving rise simultaneously to antagonistic or opposing motor impulses. If one dot is in the geometric center of the card it will immediately set up movements of orientation of the two eyes to bring the image of the dot into position on the lines of sight; that is, accommodation and convergence, a very complex and as yet rather poorly understood set of functions, come into play. The instant the second dot is placed upon the same card there is a conflict of orientation tendencies. It is impossible for the two eyes to accommodate and converge upon both points simultaneously. Both dots being of equal size and brilliance enter into rivalry for the central position. This rivalry determines whether the stimulus pattern is perceived as a whole or as an array of disconnected parts. The stronger the rivalry the weaker is the coherence of the phenomenal pattern; the weaker the rivalry the stronger the coherence. Thus the sensory and motor processes of vision at once form a dynamic interacting system in which the sensory factors not only can and do influence the motor, but the motor processes can and do react upon and transform the sensory pattern. It is fairly well agreed and established that coherence, not disjunction, is the primary state. The young child's vision begins not as an array of discrete elements but rather of

vague totalities. The basic psychological problem is to describe the mechanism of disjunction, that is, of our ability to sift out details in the unitary pattern and not to account for coherence or totality.

This view is not a new one. Purdy, Gibson, Carmichael, Bartlett, Judd and others have written in this vein. A very similar account was presented by J. P. Neul in a book published in Paris in 1904, La Vision. The emphasis on the motor aspects of the process of perceiving may be traced back to the work of a number of different individuals; to name a few: Hughlings-Jackson Mach, Munsterberg, Musatti, Washburn, Peterson, Holt, Langfeld and others.

Disjunction is based upon a simultaneous rivalry or mutual resistance between oculomotor tendencies. Unless some active influence tears them apart, the "parts" of the visual field always form a coherent unity. Purdy, quoting James, has stated that everything coheres that can cohere and nothing separates except what must.

When we look at the white card as a blank space or uniform field, and a dot appears upon it, at once the field is phenomenally divided into two "parts," a figure and a ground. Each is internally coherent, but the two regions appear sharply disjoined from each other. The basis of this disjunction is the "tension of stability" (foveal) which anchors the eye upon the figure. Immediately there is set up a motor rivalry between the figure and ground. The figure dominates. It represents a sharply defined region of constraint. Because a figure produces this selective constraint, the figure is disjoined, phenomenally, from the surrounding background. Here we have to deal with one of the most fundamental properties of phenomenal vision, namely, the structuring of the pattern of impression into a dynamic figure-ground organization.

In more complex impressions such as the case where we look out of the window upon a landscape, the figure-ground structure may attain still greater complication. Now certain objects are seen as foreground, others become sharply etched as figural in the mid-ground position, and finally a series of backgrounds extending to vanishing points complete the pattern of organization.

It is necessary to recognize that unity in the visual field arises from a principle which Musatti has called minimum variations. This principle asserts that coherence is favored by homogeneity or monotony. Many variations interfere with it. Differences promote disjunction. Lack of differences promote coherence. A nationally known artist in discussing the problem of what makes a "good" picture said that a good composition is one which possesses visual unity. The picture "hangs together," coheres, blends into a harmonious unitary whole. We may add that this attainment of coherence or unitariness is not deducible from geometrical principles, nor from the rules-of-thumb customarily laid down by the writers of books on pictorial composition.

Rivalry or disjunction obviously may be produced by inhomogeneities in color or gaps or interruptions in a pattern which would be otherwise continuous. A figure composed of spatially separated parts has an internal rivalry which increases with the distance between these parts because rivalry depends upon the way in which each element stands out from the field as a whole. Contrasting details of geometrical form can also incite rivalry. The more monotonous the figure the less the tendency of the eyes to move toward certain parts of the figure at the expense of others. Homogeneity always promotes coherence, and coherence is a necessary condition for the ease and speed of seeing.

It must be further recognized that certain so-called subjective states can accentuate disjunction or coherence. We have been able to show from experiments in our laboratory that an instruction, self-imposed or given by the experimenter, may set up either a totalizing attitude or a disjunctive attitude. It makes all the difference in the world when an individual, looking into a tachistoscope, and required to perceive and remember what he has seen in a very short exposure, "sees" an aggregate of numbers, letters, or English words, disjunctively, or whether he groups and combines them into an approximate unity. It is this factor which is so decisive in determining the so-called span of visual apprehension or memory.

Like any other habit, learning or training may set up a more or less permanent structuring of the perceptual field. This fact

is exemplified in the well-known phenomenon of habit-relief in stereoscopic vision. Two prints from the same negative and therefore possessing no stimulus disparation when viewed with an appropriate pair of base-out prisms will fuse to give a stereoscopic image possessing tri-dimensionality. We view the scene as possessing depth largely because the scene itself serves as a trigger-like mechanism to instigate an approximation to the total perception. There is operating in this case what we may loosely call habit-relief, or better stated by Thouless, a British Psychologist, as phenomenal regression to the real object. Hollingworth has also pointed out that in these cases a principle called redintegration takes place, which is to say that a part or fragment is given in the stimulus and this reinstates, by perceptual filling, the whole.

The importance of this concept of figure-ground dynamics cannot be too strongly emphasized. It is well-known, for example, that the presence of several sharply structured objects in the visual field immediately instigates the roving movements of ocular pursuit which characterizes the first stages of the search for meaning. This rivalry ends when some portion of the total pattern receives selective emphasis because it comes to dominate all the other components. Domination is achieved by the fact that when a specific portion of the visual field achieves the status of <u>figure</u>, it immediately takes on properties not possessed by those items comprising the ground. This fact can be amply demonstrated by the differential behavior in memory of the figural and groundal items in the visual pattern. The groundal portions are disjoined. Therefore they run a course in memory which is weaker and more susceptible to disruption, recombination, and standardization. On the other hand, <u>figure</u>, being coherent, tends to resist distortion, not to lose detail with the passing of time, and may actually grow stronger as time goes on.

In order to test the essential soundness of this concept, let us make a simple experiment. Every reader of this paper has, at some time or other, seen or studied Whistler s picture of his mother. Now try to recall the details of this picture. How was she dressed? Was she seated or standing? Which way does she face? Were her hands empty and folded, or did she hold some object in them? Try to describe any other objects such as pictures, chairs, lamps, etc., in the room. Try to recall accurately the details of the room opposite to the figure of the mother. Write down the answers to these and other questions of your own devising, then procure a copy of the picture and test your memory for accuracy in the ability to recall details which were obviously groundal in the original impression.

Poor visual memory is frequently attributable to the fact that the impression of an inexpert perceiver may be almost wholly a matter of ground. That is to say, it may be lacking in the degree of structuring necessary to form a sharply defined figure-ground organization. Also, we should remember that this process of figure-ground structuring is enormously susceptible to training. It is an active process in which the perceiver must actually expend some effort in the structuring of the visual pattern so that those portions which he wishes to see and to retain, attain the maximal degree of figural coherence.

It is almost impossible for this process to take place without the supplementation of verbal or linguistic processes occurring at the same time. The mere fact that we give a name to an object is capable of completely changing the course of this process in perception, in retention, and in memory. Thus a part of the ground consists of verbal-motor responses which precede, accompany, or follow the visual impression itself.

We must also remember that part of the ground which constitutes the setting or framework in which visual impressions are seen embodies the postures, tonus patterns in the skeletal muscles, and the aggregate of other motor processes going on at the same time.

All of the above considerations force us to take a much broader view of the act of seeing than has hitherto been customary. The sensory components in the process are only partly responsible for the course and the end product of any act of seeing. <u>The executant motor processes</u>, that is <u>the things we do</u> in response to the stimulus pattern, are highly determinative of <u>what we see</u>. These processes may vary from simple class-

ification, or giving the thing seen a name, to the most elaborate, systematic, investigatory analyses.

It is fair to say in conclusion that the practice of optometry in the years to come will utilize these concepts to greater and greater advantage, not only in reshaping diagnostic procedures, but clearly they will be indicated in all remedial or re-conditioning training work. It is not unlikely that those who have difficulty in learning to read or to spell, for example, are merely the victims of very inexpedient habits of the structuring of their visual perceptions. Just as the illusions of reversible perspective become understandable when we conceive them as patterns in which the figure-ground relation is readily reversible, so it may well be that the failure of individuals to perceive what we should like them to perceive becomes a case of the failure to formulate a definite or sharply etched figure upon a ground. We shall have occasion in subsequent papers to refer again to these and some further considerations of <u>perceiving</u> as <u>essentially</u> a <u>non</u>-sensory <u>function</u>.

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

 Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

SEEING AS VISUAL PERCEPTION: II

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In the preceding paper we set down a few facts relating to figure-ground organization and its importance in perception. It was pointed out that what we see is intimately bound up with the kinetic and motor systems at our disposal. When a child views a new object for the first time his search for meaning is essentially manipulatory. He must handle the thing and put it through its paces in order to understand it. How it works or what it does carries the fullest significance for him of what it means or is. In the science of language, if we trace the genesis of work meanings, we find that the first or most primitive stage is in terms of a recreation of activity. For example, a fork is defined as "something you eat with," not as a three tined curvilinear instrument, made usually of silver, and comprising an elongated handle, possessed of certain specific dimensions and decorated with certain forms of artistic engraving,--in a word, a definition which comprises a description of the object in terms of such secondary properties or attributes as size, color, shape, physical dimensions, materials, form, design, etc.

We must recognize the importance of the fact that the earliest forms of any language are gestural, postural, and mimetic. At this stage of the development of language we do the same thing that the savage and the deaf man and the silent movie actor does, namely, we convey meanings to others by the process of acting out or symbolizing the abstractions which we wish to convey to another. Just as in the beginning, the motor component is the primary thing in the execution of language, so it is also the primary thing, either directly or in some derived form, in the comprehension of language. The basic foundation for all perception lies in those adjustory responses which shape the course and give the final stamp of meaning to space, form, movement, and perhaps to all other cognizable qualities.

In an earlier paper it was suggested that an analysis of the process of visual perception reveals the fact that no visual experience is perhaps ever wholly visual. All of the afferent impulses from sight, hearing, and touch are correlated in the mid-brain. In adulthood much of the ground in any visual percept is constituted of sensory components arising from the skin, the muscles, the articular surfaces of the joints and from hearing. Our estimation, for example, of the visual third dimension, that is, the nearness or remoteness of any object, is in part in terms of image, size, light and shade, intervening objects, motion, etc., but it is also in terms of foreshortened traces of response mechanisms that have been active at some previous time. If I look out of my window at a neighboring building across the campus, its distance is partly derived from considerations of such things as whether I could hit it with a rock, how long and how many steps it would take me to walk to it, or roughly how it compares to some more or less exact notion I have of a unit hundred-yard length.

For those of us who deal directly with vision and visual problems, it is necessary for us to keep these considerations constantly before us. We must never lose sight of the fact that the visual process is a distance-receptor process and therefore represents a late stage relatively in the biological evolution. The possession of a distance-receptor such as the eye enables us to locate the position of objects in space with much greater accuracy than can be done by any other sense organ. This is true only if we recall that accuracy of visual location depends upon two things: first, the fact that from babyhood on, the apparent positions of objects in space are always checked and verified by movements made with the hands of a manipulatory type; and secondly, the excellence of localizing ability derives from the hardness of objects. Light waves bounce back from ob-

jects and provide the possibility for collection and sharp dispersion at the retinal boundary. Sound waves, on the other hand, reflect and refract quite differently. However, persons who have lost eyesight completely learn to discriminate the size, shape, and position of objects with an astonishing skill by learning how to interpret the patterns of sound reflected from many classes of objects found in the immediate environment. The limits of distance, of course, are quite strikingly dissimilar.

This question of localization in space is a much more important one than appears at first sight. As I look out my window the large beech tree is located out there; not at the retinal surface. It is a fact of the first order importance that objects are seen, not at the position in space where they produce the primary change in the reacting organism, that is, at the retina, but we always refer them to a position distant from the body. This is the fact of external reference. If you lose a golf ball in a shallow, muddy pool, and probe for it with a niblick, as soon as the club head strikes the solid ball the shock is felt not at the point where the shaft of the club touches the hand but at the distal extremity of the club. Thus we tend to perceive, to localize and to refer objects to the positions where important activity takes place.

This function is not a native gift. From babyhood to adulthood external localization grows and develops in conformity with the developments of locomotor and handling responses.

We may come to a clearer and better understanding of the visual perception of objects in space by the examination of a still more primitive sense organ, namely, the skin. If a mosquito stings you upon the right forearm midway between wrist and elbow, how are you able to localize the point stimulated if no visible traces of the sting remain? We have studied problems of this sort in the laboratory. Suppose we begin with a comparison of the accuracy of localization in children and adults. Using small areas on the back of the hand and on the volar surface of the forearm, we stimulate with a gentle pressure a small spot, a fraction of a millimeter in diameter. The subject is required to set down upon this spot the point of a small surgical applicator made of wood and about one-half millimeter in diameter. If we repeat the practice sessions day after day, we find that large practice effects are shown both in the case of children and adults, both on hand and forearm. The errors reduce very rapidly. Children are not only more accurate initially, but show much greater and more rapid decrease in error than do the adults. In fact, the average error for adults on the forearm after eight days of training was slightly less than the average error for the adult hand on the first day. This simply means that while the error on the arm was 25% greater than on the hand at the beginning of the experiment, after eight days of practice the skin of the forearm gave no greater error than that of the hand at the beginning of the experiments. We are forced to conclude from this simple observation that cutaneous space if not fixed anatomically but is capable of great change from training or practice.

A further significant fact found in these experiments was that the difference in the accuracy of localization between the hand and forearm in the adults are significantly greater than in the case of children throughout the first eight days of the practice. During the first two days the children localized more accurately upon the forearm than upon the hand in contrast with the opposite state of affairs with adults. The children showed marked superiority to the adults in localizing both initially and after practice or training. The difference amounted to about 300% superiority in favor of the children. These results were subjected to very careful study in order to discover whether the significant differences found could be attributed to such factors as the proportional sizes of the skin surfaces, etc. It was finally concluded that the answer had to be sought in the making of a new series of experiments. It should be borne in mind that all localizing was done with the subjects, both children and adults, wearing a blindfold. In order to find out to what extent vision is instrumental in determining the magnitude and direction of the localizing error, a second set of experiments was made comparing congenital blind with seeing children and adults. Here we found, using the same methods, that blind adults were superior to blind children and also to seeing adults, and that seeing children were superior both to seeing

adults and to blind children. Superiority of the blind adults over blind children must be associated with the increased discrimination which comes from more extended practice. The inferiority of the seeing adult to the seeing child must, therefore, be due to a shift in the method of localizing which comes with distance-receptor dominance. At about the age of puberty, we soon depend upon vision for things which previously had to be verified by the contact stimulation of the skin and from the muscles. Blind adults were significantly superior in localizing upon the skin to seeing adults. On the other hand, the blind adults made almost no noteworthy gains from practice after the second day, while the seeing adults blindfolded gained rapidly in accuracy throughout the whole course of the practice series. An equally striking contrast is noted in the case of the comparison of the blind and seeing adult forearm. Here the blind diminish progressively in error with successive practice throughout the first eight sittings, but the seeing adults show no improvement for the first five days and then suddenly increase with great rapidity during the rest of the experiment. Blindfolding a seeing person does not make him equal in this function (locating a point stimulated upon the skin) to a blind adult. Blind adults with much larger hands and arms localize with the approximate mean error of the seeing children. No neurological or psychological evidence to support the notion that accuracy of localization is to be accounted for by the distribution of receptors in the skin and fascia was found. Dallenbach found that the phenomenal distribution of temperature-sensitive points showed no correspondence to the position of specialized nerve endings in the skin. Accuracy of localization does not vary with the density of receptors per unit area. Cole showed that regions which have, so far as is known, equal or nearly equal density of fibers in the superficial tissues have widely differing average errors of localization.

In view of these considerations, we must conclude that it is extremely unlikely that age differences are due to boundary conditions. If we assume that the surface areas of adult and child stand in about the ratio three to one, then no correspondence with this fact could be found regarding the size of the relative errors. When seeing children utilized their least effective method of localizing (visual), and seeing adults utilized their poorest method (tactual-kinaesthetic), no true differences in the accuracy of localization were found. Nor was there a true difference where the best methods of the two groups were compared. Thus, the apparent large differences in accuracy between children and adults and in the case of the congenital blind and seeing, reduce almost wholly to the question of the influence of vision upon the function of localization of points stimulated in cutaneous space. The space of the skin thus depends upon vision just as the space of vision is inextricably interwoven with other sense modalities.

Psychologically there are many spaces. In physics there is but one. The position, form, size and relations of objects in space has been studied quite extensively. Some of the facts gained from these studies are important for optometry. Tachistoscopic vision and stereoscopic vision are cases in point. Our next paper will deal with some interesting experiments of this type.

Psychology of Vision

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by Samuel Renshaw, M. A., Ph. D.
Ohio State University

OPTOMETRIC EXTENSION PROGRAM

TACHISTOSCOPIC STUDIES ON VISUAL PERCEPTION

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We have called attention in previous papers to the primary importance for perception of the organization of the visual field into a figure-ground structure. Perception really consists essentially in the emergence of a figure upon a ground.

Figure has shape and appears solid and highly structured. Ground is weak as to form and exists as undifferentiated substance. Generally, figure has surface color; that is to say, its color is localized on its surface and is resistant to penetration. The color of the ground is filmy, soft and yielding, and not sharply localized. Spacially, the figure appears separated from its ground and this separation may be seen in front of or behind the actual surface of the ground. Figure usually possesses sharp and strong contour, but this is not a universal and essential property of figure. Where the figure is uncontoured and of equal brightness with the ground, although differently colored from it, the figure will appear also unstable and ill-defined. When contour is introduced, the figure becomes stable, well-defined and localized, and with its color hard and glossy rather than soft and spongy. Figure generally has "thing character" and is more insistent and more central in awareness and is more likely to have connected with it various meanings, feelings and aesthetic values. Figure is named sooner and remembered better because of its greater strength in impression.

Wever* has studied extensively the phenomenon of the emergence of figure from the ground in perception. Of the eight stages which he describes, the first four, which are necessary to the emergence of the simplest figure, are completed in a period as short as ten milliseconds. These stages are as follows:

1. Heterogeneity between the figure and ground, each of which forms a unit;
2. A minimum brightness difference between the two which gradually increases; this stage is simultaneous with 1;
3. A range of separation which appears when 2 has reached a certain magnitude and eventually narrows down to become the contour;
4. Shape, however, appears before the contour is definite; as the figure-ground experience progresses, 5 and 6 put into appearance and may be completed in a further period of 7 ms;
5. Protrusion of the figure out and away from the ground;
6. Definite depth localization of the figure;
7. Surface texture of the figure, filmy texture of the ground;
8. Halo around the figure which is a simultaneous contrast effect.

The durations given by Wever are minimum figures.

Other investigators have shown that the time necessary for the figure to become perceptible varies with the complexity and degree of meaning of the figure. A special type of apparatus is used in studies of this type. A tachistoscope is a device which enables the experimenter to control the duration of the exposure, the size of the visual field, the quality and intensity of the illumination, the size of the eye-opening, the set or instruction under which the observer operates and a number of other similar factors. There are a number of different designs for instruments of this type. They differ from one another largely in terms of the particular variables which one wishes to control. Where exposures of very short duration are to be used, it is, of course, quite necessary to control accommodation and convergence. In our instrument this is accomplished by passing a small point-source of light through the card containing the test object. A small projector controlled by the observer

*American Journal of Psychology, 1927, 38, 194.

places a spot of light containing a black cross about three millimeters in diameter directly over the point-source which is then immediately extinguished. The observer, although partly dark-adapted, fixates the cross at a warning signal which is given about one and one-half seconds previous to the exposure.

The exposure is controlled by two types of light-chopping devices. The first is a gravity focal-plane shutter. With this we are able to secure exposures accurately from one-half millisecond to 275 milliseconds. The accuracy of the time of exposure is checked by mounting pieces of highly sensitive photographic material on a disc driven by a synchronous motor which rotates at the rate of thirty revolutions per second. The angle subtended by the image of the light track then indicates the actual time of exposure. In our instrument, the difference between such actual times and the calculated times is less than 2%.

The second method is a magnetic shutter. The blades of this shutter are activated by a toggle lever. These shutter blades part in the center of the field. An appropriate lens system flattens the beam from the illumination source to a band of light which measures 3 x 5 mm. For exposures of a quarter of a second and over, the lag in the magnet is negligible.

Our earliest studies on the speed of visual perception were made in 1933-4. At that time, Dr. Salo Finkelstein, a Polish lightning calculator, visited our laboratory. This man could perceive and remember lists of numbers from exposures shorter than had ever been recorded for any human being. The writer became interested in the problem of the nature of the process utilized by this individual in the extreme rapidity with which he could memorize numbers as well as perform the usual kinds of calculations. The preliminary series of studies on this problem led to the development of better apparatus and a series of studies on the perception of forms in short exposures which are still in progress.

One of the things revealed to us by this kind of a study of vision is that by means of the short exposure we can study the process of perceiving in its early stages by stopping it after the stimulus has been acting for any duration we select. Numbers are an excellent material because they can be presented in either small or large groups and they have no hampering associations.

One of the first important problems which we have studied extensively is the relation between the length of the material exposed to the eye and the time required to perceive and reproduce it. The amount of material which can be reproduced in a single brief exposure is generally called the span of visual apprehension. The number of digits, letters, words, or figures which can be apprehended in a single exposure has been said to be limited to about seven. The presumption has been that the chief limiting factor is the size of the image at the retina in relation to the size of the macula. We have been able to show that the paramacular field can be greatly extended through training. 17-letter English words, double-spaced, which subtend a visual angle of about 14 degrees at the lens, could be perceived and reproduced correctly in an exposure of one millisecond. Consider what this means in relation to the fact that the latency of the visual mechanism is of the order of 20 to 30 ms. Such speed in visual perception is, of course, only possible under the condition where the material presented to the eye is seen as unitary.

If we expose letters in 36 point type on 5 x 8 white cards, we may determine the speed with which digits of varying lengths can be perceived. Dr. Finkelstein established the following records which are a few taken from a larger number established in the investigation.

Number of Digits	Time of Exposure in Seconds
8	.003
9	.030
10	.264
11	.531
12	.824
14	1.16
16	1.73
18	2.44
20	3.55
21	4.43
25	7.01
32	25.4
42	45.0

These figures are worthy of careful study. They represent essentially world records. The average individual will require from 20 to 70 seconds, or more, to perceive and memorize a 15-digit number the first time he tries it The magnitude of the gains from practice is the first striking fact revealed by these studies. It will be noted that the addition of a single digit to 8 digits increases ten-fold the time required for visual perception. Further, whereas 8 digits requires but three thousandths of a second, 16 digits requires almost sixty times as much exposure. If these figures are plotted with the number of digits against the logarithms of the times of exposure, it will be noted that there is a sharp change of trend in the curve at 11 or 12 digits. Up to this size of number, digits are perceptually amalgamated into a unitary impression without grouping. Numbers containing more digits than this are seen first as aggregates of smaller sub-groups. The process of training means that these groups undergo a gradual expansion. For example, 16 digits may be seen as four groups of four; as five groups of three plus one, and so on. It may also be seen as two groups of eight, or as a group of ten plus six, or as a unitary, coherent group comprising all sixteen. If we photograph the eye movements of the perceiver early in the stage of his practice, we observe the characteristic stepwise movements seen in ordinary reading. When we have trained this same observer to the point where he now perceives in a tenth to a twentieth of the time originally required, photographs show that the eye makes a single sweep, without pausing, throughout the expanse of the visual material, even though, in phenomenal experience, the learner may still introduce subjective grouping. There does not seem to be any correlation between perceptual units and the movements of the eyes.

When we use lists of consonants, meaningless geometrical forms or meaningful English words, we get essentially the same kind of results. The process is the same regardless of the contextual material.

Many interesting and important facts were revealed by an analysis of the observer's behavior before, during and after the exposure. The tendency of the novice is, of course, to name or pronounce what he is seeing concurrently with the visual exposure. All observers soon discovered that this provided a serious handicap. Verbal activity during the exposure weakens and inhibits the visual impression. Furthermore, at the termination of the exposure, if the attempt to reproduce by speech what was seen is begun too quickly or too slowly, the amount and accuracy of reproduction diminishes. A good rule to follow is to advise any person, who wishes to use vision with maximal effectiveness, to engage in no other activity during the period of visual impression.

The question may arise as to whether the above results, secured upon a world famous expert in dealing rapidly with numbers, do not represent a function different from that found in ordinary persons. In order to check such a postulation, we trained a number of ordinary university students in order to determine how much we could extend their capacity to rapidly memorize visual material in short exposures. About a dozen such cases were recorded. In every case, the shape of their curves is identical with that given in the above figures for Salo Finkelstein. In every case, also, as improvement progressed the curves of the student moved gradually in the direction of the limits set by Finkelstein; and in two cases of extended practice, we not only trained ordinary students to equal Finkelstein's best performance, but in a few instances they exceeded him. Here we have a fact of great importance. The limit to which visual perception can be extended through proper training is still unknown. We are certain that it can be improved to an almost incredible extent provided the observer is willing to work, and provided he utilized the proper methods. The difference between the expert and the novice in the rapid and accurate perception of visual material is the same difference between the expert and the novice in the performance of any skillful act. We have to learn to see just as we have to learn to swim, to play the piano or to speak French. This can be done with skill and efficiency or it can be done haltingly and ineffectively. When we train children to learn to spell English words by replacing the wasteful and inefficient disjunctive method of seeing words with the proper method of visual perception, spelling difficulties disappear. Not only does a child spell accurately and easily, but he comes to enjoy spelling. An incidental by-product also is that his rate of reading and index of comprehension automatic

ally show a corresponding improvement. Once and for all, let us be sure that we do not make the mistake of assuming that this skill in seeing is the development of a so-called photographic eye. There is no such thing as a photographic eye. If I were to show you a line drawing of an unfamiliar meaningless design for a brief exposure and ask you to draw or reproduce what you saw, then took from you your drawing and gave you another sheet of paper and another exposure and had you draw it again and again, after as many succeeding exposures as would be required for you to reproduce the figure so that it would duplicate the original, you would find that the development of your perception of the shape of this figure is an enormously complicated process. It is literally true that we see only in part.

It is also true that we tend to see and reproduce as much or more the frames of reference which we bring to the stimulus situation as the actual test object exhibited to the eye. If, early in the series of exposures, we give a name to the figure, then the tendency will be to stereotype and conventionalize subsequent drawings to fit the pattern rather than to reproduce what was seen.

My object in calling attention to these facts is to impress upon optometrists again the importance of psychological optics. Many persons who consult you professionally are the victims of visual difficulties which are non-refractive in character. To the extent to which you can understand and control these functions you can render a superior service to your patients.

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

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OPTOMETRIC EXTENSION PROGRAM

READING AS A SPECIAL CASE OF PERCEPTION

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Language constitutes the distinctive form of human behavior. The possession of an easy and certain means of communication has been largely instrumental in the production of our human culture. No other form of human behavior is as complex and intricate in its sensory-cerebro-motor organization as reading and speaking. Learning to talk, to read, and to use other forms of linguistic expression, therefore represents the most difficult single undertaking that any child ever undertakes. It has been pointed out repeatedly that perhaps the major proportion of the average person's school activities is simply devoted to gaining facility in the use of the mother tongue.

Because of its great complexity we should expect to find wide variations in the degree of mastery exhibited by various individuals, and because of this complexity we should expect to find, and do find, many types of disorders of the complex function. In the present paper we shall concern ourselves primarily with those which involve psychological factors.

Let us begin by realizing clearly that the earliest forms of language were not written or spoken, but consisted of gestures, postures, and mimetic and dramatic attempts to reproduce the motor patterns which would serve as the symbolic equivalents of the things perceived. This early language was, therefore, essentially motor and manipulatory Meanings were simply the successful instances in which there could be reincorporated at a later time in the understanding of another person some perceptual identity, or empathy, always in motor terms. The essential soundness of this fact is further indicated by an examination of the development of language in any individual. A new object is defined in terms of its uses, or what it can do, or what it does to us. As similarities arise in dealing with types of objects which are broadly classed as the same, we find it convenient

classification which represents the entire group of things or processes forming this class. We still further refine the general classification into an abstrction which designates still less specific members or properties or attributes. Such words become the condensations or symbolic representations of not merely single instances of experience, but whole trains of events which may run a course in time and which consequently can be rendered communicable to others because we have developed this shorthand method of representing these events or relations.

It must be clear that language of any type grows out of the necessity for individuals to act co-operatively; that is, for the sense organs of one individual at some times to utilize the motor organs of other individuals. It is perfectly proper, therefore, to speak of language as a <u>compound habit</u> because there is always implied the notion that any linguistic act is never complete and perfect until the symbol expressed by one individual as speech, gesture, or writing, is perceived and identified by another individual. Operationally, a perfect language would be one in which the speaker or communicator would succeed every time in conveying to the recipient the perfect meaning the originator seeks to convey.

It is a fact of great importance that this theory is rarely attained. It is well-known, for instance, that in childhood understanding runs well in advance of the ability to produce expressive linguistic forms. Young children understand far more than they are able to express in speech or writing. Put another way, we can say that the mechanics of language production lags behind the processes of interpretation. By the time a child has reached his sixth year and is therefore ready to begin his formal education, one side of his language development has proceeded far in advance of the other. It should further be borne in

process. As such it undergoes such transformations as the result of proper practice and training that the mechanisms involved in its early stages are not the same as those which are observed in the same individual after he has been trained. Before there has been any formal training, the tendency of every child is to perceive things, events, and relations in the world about him in the manner which we have described as coherent seeing. If now he starts to learn to read, he is frequently forced to adopt what for him is the utterly unnatural procedure of perceiving abstract and rather meaningless symbols (words) as disjunctive perceptual experiences. If this process continues and if it is accompanied by poor understanding, the longer this relation is extended the wider becomes the gap between the end product, namely, to understand what the author seeks to convey, and the key to the whole situation, which is the visual-verbal perception of the symbol which should produce the reconstitution of clear meanings in the mind of the perceiver. Let us again re-emphasize the fundamental fact that language not only began as motor, but remains essentially as a skillful motor function, even in its utmost stages of development. Such things as visual and auditory imagery are almost never found in these processes where they are operating smoothly and with some degree of skill. Where images do occur, they arise secondarily and consequentially to the essential motor groundwork which is the essence of the process.

As a consequence of the dissociation introduced by the child himself or by his teacher, we find, practically without exception, that a youngster who presents a problem because he cannot spell or read effectively or understand written or spoken language easily and well, presents almost without exception an emotional problem. Thus because when confronted by the necessity of reading a page and understanding "what it means," he is thrown into a state of tension which leads to blocking, and there is no surer way to disrupt this complex function. In fact, in any learning enterprise the assumption of a defeatist attitude actually sets in motion the postures and the implicit movements which conduce to erroneous and failing acts.

Based on many observations it is our conviction that the first important step in the treatment of any dyslexia or other reading or linguistic problem is to remove the bad habit which arises from the fact that every poor reader or bad speller is keenly conscious of his own disability the instant he is called upon to perform this function. This means that even his initial efforts must be expressed in the face of a more or less serious emotional blocking. We believe that the first thing to do is to remove this bad habit, and to convince the individual that reading can be done easily, fluently, and practically without effort. We try also to convince him that he can do it. So the first step we take is the very simple one of showing to the individual a simple visual form for a long enough time so that he can see it. As a check or test of whether he has seen the exposed figure, we may require him to recognize the one exhibited from among a group of other similar but different figures. The exposed material may be as simple as showing shapes like triangles, stars, squares, half-moons, or one- or two-place numbers. This may lead to the use of single letters or short easy English words. After a few practice sessions the time of exposure is gradually reduced and the length and complexity of the material is gradually increased, and since the word failure and the fact of failure never enter into the situation, the learner quickly builds up confidence in his ability to visually perceive symbols. Many children who have great difficulty in learning to read also have great difficulty in being able to quickly and accurately perceive shapes or visual forms. It can be set down as a fact that whenever an individual can really see an English word he can spell it. By seeing I mean that he must recognize and produce the word not as an aggregate of single letters. The word becomes an essential unity. Skill in seeing means that the whole word, regardless of the number of letters comprising it, is seen as a single shape. When this skill has been attained, learning to spell words becomes surprisingly simple and invariably accurate, and at the same time reading will be found to benefit proportionately without any special attention being given to it. The perception of groups of words comprising sentences or phrases can become a coherent, perceptual unity, just as an aggregate of single letters can and does become a unitary word.

It is quite important, if we are training

an individual to see visual shapes, to restrict the activities of the individual, particularly in the early stages, to the single business of seeing. We know that if a drawing (consisting of a half-dozen short, straight and curved lines forming a meaningless figure) is exposed for one-tenth second and the observer required to draw it; and then if the figure is re-exposed and re-drawn and this process continued until a perfect replica is produced, the process of building up the final exact perception of the figure is a very complex process, and goes through a number of well-defined stages before the shape is really seen. One important fact arising out of research studies of this process of the building up of visual percepts, was the discovery that naming, pronouncing, or any other verbal motor activity during the visual impression period, operates to hamper or interfere with the ease and accuracy of visual perception. When we train an individual to see, therefore, speech activities, gestures, and other motor forms of expression should be reduced to the barest minimum. The best procedure seems to be to acquaint the learner with these facts and advise him to sit erect and alert and do nothing else but to take a good active look at the exposed figure during the time of exposure. A second important fact is that a short time should elapse after the exposure before the individual engages in any activity of speaking, drawing or other form of reproductive expression. Here, curiously enough, the process of being able to remember and reproduce what was seen is interfered with if we start too soon as well as if we wait too long. As we become more and more trained, however, this time factor seems to become less and less important. This second step aims to develop an active dynamic motor attitude in the perception of visual shapes. This function is enormously susceptible to training as I tried to show in the paper just preceding this one.

At this point, it may be of interest to remark that memory is frequently blamed for faults which it does not deserve. Often times children cannot read and spell for the same reason that when a person walks into your office to whom you have been introduced only a few hours earlier and you cannot recall his name, even though you instantly recognize his face, where you met him, etc. Let us remember that in this instance the failure <u>is not the failure to remember</u> the man's name. The failure lies in the fact that when you had the opportunity to <u>learn</u> his name you were busy doing something else. This something else, on careful analysis, probably turns out to be making small talk, sizing up his clothing, or what-not.

After we have reached a sufficient stage of proficiency in the skill of visually perceiving form, then pronunciation, phonetic training, grammar, and such things, may be introduced as the proper diagnosis if the situation indicates. It should be remembered that reading consists essentially in not only the mechanical ability to see the shapes of aggregates of words which are the symbols of the types of motor sets which we call ideas, but even the most perfect possession of this skill would avail us nothing in the absence of the essential perceptual frames of reference which are often broadly designated as intelligence, background of experience, insight, understanding and the like. It has been pointed out again and again that the principal causes of difficulties in learning to read and spell are the non-refractive ones. In fact, the curious paradox seems to hold that those individuals with poorest eyesight tend in the large to be the best readers and spellers. It may even go so far that the possession of a certain none-too-large degree of myopia may be almost a guaranty of good scholarship. The difficulty in most cases of children who present these problems is to be found in the fact that habits of slovenly, piece-meal perception have been called upon to perform the exacting and intricate function of perfect language, and, as anyone could predict, the end result is failure,--failure which continually grows upon itself. Bad reading oftentimes is but a mere symptom of bad habits of work, play, and other fundamental activities induced by improper training even from early childhood. Optometrists and educators alike should, therefore, recognize that it is of the utmost essential importance to secure the full, whole-hearted and understanding cooperation of the parents of a child if progress is to be made, and this must be done even if it necessitates a radical readjustment for the whole scheme of life for the youngster. Do not look for a few simple rules to cover the technique of treating all the many distortions of perception. Every case

must be handled individually. Great emphasis must be placed upon etiology in these cases. From it you may often deduce the principal source of the difficulty.

There are many interesting technical facts about the mechanics of reading which are just beginning to be understood. Take, for example, the question of the function of the two eyes in reading. We have been urged to believe by some people that whenever the two eyes fixate and pause simultaneously upon a single point in a line of print, then jump by smooth movement to a second fixation pause, and so on, that most reading difficulties will disappear. In other words, the argument seems to be that faulty eye movements are a primary cause of bad reading. Suppose we look at the thing the other way around and say that if ineffective movements of the eyes are found, they are a consequent of bad reading and not a cause which produces it. In our laboratory, for example, when we photograph the eye movements of students trained to perceive with high skill in tachistoscopic exposures, we find that the eyes sweep across the line of printed material in a smooth ballistic transit, without any pauses, regressions, or fixations whatever. When this same person reads a line or paragraph of familiar text, the number of fixation pauses usually runs from three to six or seven per line. Stromberg has shown that in good readers even the two eyes do not necessarily fix upon the same point in the printed line during reading. Frequently the variation is as much as ten or twelve letter spaces. In the same line of print the fixation points often reverse their relative position, that is, whereas the left eye leads in the beginning of the line, the right eye may be the leading eye at the end of the line. The author concludes tha[t] this variation in fixation points suggests either that the stimulation of the corresponding points at the retinae is not neces[-]sary for single binocular perception or that vision is suppressed in one eye during reading perception.

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

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OPTOMETRIC EXTENSION PROGRAM

SOME FURTHER CHARACTERISTICS OF VISUAL PERCEPTION

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When we read a paragraph or a page, how accurately do we understand and act upon the contextual material set down by the author? Here we see a close relation between the process in reading and the process of perceiving as we observe it in the laboratory in the more simple types of experiments. If I show an observer the figure of a square with one side omitted in a very brief exposure and later ask him to draw what he has seen, the usual response is to draw a completed square. If I show eleven small black dots arranged as the hours on a clock face but with the four o'clock one omitted, the observer will draw twelve small dots, filling in the missing one. If he is quizzed as to the accuracy of his reproduction, he will probably strongly insist that all twelve of the dots were there. These are simple instances of <u>perceptual filling</u>. We must remember that the process of perception is a unitary whole. When we see a landscape or a face the unity of the process suppresses details and causes the final interpretation to become not what it is, but what it should be. This is another way of saying that the whole course of the perceptual process is strongly determined by such things as instruction, set, purpose, intention, desire, temperament, etc. If a name is given to the visual pattern, very many times this not only gives certainty and satisfaction to the perceiver, but with complex figures naming plays a very distinctive role. A name is usually a classificatory generalization, so that the course run by perception tends to follow more the classification set up by naming than it does that imposed by the visual patterns impressed upon the retinae. Thus, we remember seen figures as intrinsic realities, that is, <u>that</u> the thing exists, and often <u>what</u> it is, but we frequently forget <u>where</u> it is. Thus the properties of location in space and time, being weaker, are often the first things to disappear. This function, however, is very susceptible to training, and consequently the whole process of selective emphasis upon some parts of the total process can be controlled to a large extent by appropriate training methods.

Closely related to the fact of perceptual filling, and perhaps derived from it, is the fact that even in the case of simple figures interpretation often runs ahead of presentation. We always see more than is furnished by the stimulus, and much of what we see is not seen at all, but is derived from other sensory and motor sources. If the material is more or less unfamiliar the active nature of the process of perceiving is immediately revealed. There is a searching and matching for the best possible meaning. This usually begins by seeking analogies. The answer to the question "what is it?" is usually in terms either of something which is like the perceived object, or else in terms of what it does. Naming often follows, and because all features cannot be seen at once, a confident observer justifies himself and reports or sets down more than was actually present, while the more cautious ones doubt and diminish detail. Thus temperament and attitudes are of great functional importance in perceiving and remembering.

From the more important studies in the various laboratories, we can state with a considerable degree of assurance the following well-established facts about the process of visual impression:

Accurate perception and recall is the exception, rather than the rule. Gibson has shown, for example, that if simple curved lines are shown tachistoscopically and the observer is asked to reproduce them, they are always seen and reproduced with diminished curvature. Curved lines are seen as much straighter than they really are. If we test children and adults by the method of serial reproduction, other striking facts appear. This method follows the simple plan that if I show you something today, I may test you for your

immediate recall at the end of a few minutes after the conclusion of the impression. I then arrange a regular schedule of repeated tests at weekly or monthly intervals, and carefully compare the changes in the reproduction introduced by the passing of time. Suppose I have you read a paragraph containing ten details of fact, or ten steps in an argument leading to some definite conclusion. Experiments have shown that from the very first reproduction until there has been almost complete forgetting, the retained impression is constantly being changed and transformed. The tendency is towards simplification. Details are omitted and inventions are introduced, thus changing even the whole trend of the argument. It is not uncommon that a student in a college class may listen to a lecture and set down in his notes a conclusion which is the exact opposite of that carefully and systematically expounded by the lecturer. This is particularly true if the argument is one which opposes or runs counter to the training, interests, beliefs, and prejudices of the perceiver. Interestingly enough, in view of such facts, one wonders how the index of comprehension in many of the existing tests of reading comprehension should be interpreted. Certainly there is no reason to expect any one to have perfect accuracy in reproducing all the details in a page or even a paragraph of moderately complex material. If readers are trained to reproduce the exact pattern of the context, then we approximate the same stage psychologically as that of an expert stenographer or reporter who takes down in shorthand a lengthy discourse, but at its conclusion is utterly incapable of retelling a single idea which he or she has heard. Some care must be exercised, therefore, in the interpretation of either rate scores or comprehension scores obtained from applying standardized reading tests to children and adults. Lawyers and ministers sometimes differ on the meaning of what seems to be clearly written English.

If a visual perceptual impression is to produce an effective result, some immediate motor consummation is essential. This principle can be illustrated rather simply. If we watch a person who suffers a rather conspicuous hearing loss attempting to understand our speech, we may observe that the words spoken to this person produce lip movements which indica[te] that the same motor processes are goin[g] on as if this person were repeating ve[r]batum what he hears. Again, if I read [or] hear an instruction at ten o'clock in [the] morning to call a certain telephone nu[m]ber at three o'clock in the afternoon, [the] ultimate successful consummation of th[is] instruction will largely depend upon wh[eth]er I make some immediate motor adjustme[nt] which can, at the later time, serve as [an] effective substitute for the stimulus w[hich] we assume to be absent at the required time of consummation. In such a case, [I] may make a written notation; I may spea[k] internally, thus repeating the instruct[ion,] or I may tie a bit of red woolen yarn a[round] my little finger. The precise nature o[f] the immediate act seems to be relativel[y] unimportant. The psychologically impor[t]ant fact seems to be that I make some i[n]tervention in my usual course of behavi[or] which serves as an effective substitute for the stimulus in the delayed reactio[n.] Speech and language are the mechanisms which in adult life we rely upon to a v[ery] large extent for the successful consumm[a]tion of such instances of perceiving. E[x]periments in our university in the teac[h]ing of modern foreign languages have am[ply] demonstrated that where the teaching me[th]od follows these principles, the studen[ts] not only make phenomenally rapid progre[ss] but language learning becomes easy and pleasant.

The essential pattern of perceiving is the discrimination of a figure on a gro[und.] All of the details of the dynamic inter relations of figure and ground in visua[l] perception have not as yet been discove[red.] However, we do know that the figure gro[und] organization in visual perception is a type of skill which must be acquired if we are ever to attain the maximum effec[]tiveness of this function. In his stud[y] on the visual perception and reproducti[on] of digits in our laboratory, Knight has described the successful act of reprodu[c]ing what was seen as follows: "Most of the constitutive performance will alrea[dy] have taken place before the number is e[x]posed. But this calls for a very high order of skill. Not just anyone can do it. The exposed digits have a value as signals in the super-performance, even when peripherally given and probably eve[n] if the eyes are in motion, which they la[rgely are] entirely for the novice." Gaining skill

in visual perception was found to depend largely on the creation of an attitude or mode of attack which is set in motion even before the stimulus signal is presented to the eyes and which, to quote Knight still further, "may exert more influence on emergent figure than such field conditions as equality, proximity, closure, and good continuation." The articulateness of figure is underlain by executant skill of greater or less precision. Ground is seen as the character and pitch of prodromal activities, as well as conditions in the sensory field. Unusual memory such as the ability to reproduce seen materials correctly, after exposures which would be hopelessly too short for untrained observers, is universally reported as plainly motor in character. This motor performance is characterized as precise, fluent, economical of effort, and distinctly gratifying in an aesthetic sense. Dependence on imagery in the attainment of such instances of highly skillful visual memory is uniformly abandoned. Images eventually come in cases of debate, but in general they trail the motor performance. Knight found that in extended practice on the same class of materials that his subjects developed highly individual schemata, whose operation could be described with some success from the character of the erroneous responses made by these subjects. Hardly any two individuals developed precisely the same pattern of performance in the highly complex, skillful act of visually perceiving the exposed materials, whether these comprised digits, consonants, English words or simple geometric shapes. This means that we must not look for single, simple rules which will prove equally effective in the training of different individuals to perceive most rapidly and effectively.

Certain impressive facts have appeared during the six years we have been experimenting with the visual perception of forms, and these facts may be applied in the more effective teaching of children to spell and to read. It is safe to say that one of the principal factors in almost all cases of slow and inefficient reading or spelling is the inability to perceive visually the material presented. I want to strongly emphasize this fact: that the highly trained subject who memorizes a 21-digit number in 4.372 seconds, whereas in his early trials he took 90 seconds to accomplish the same task, has not merely gained in speed. Speed is but a single dimension of the function which has become, during the training, transformed into an entirely different process. We feel quite safe in our laboratory to assert that the highly practiced subject <u>sees</u> the material exposed to his eyes by utilizing an entirely different set of functions than those employed by the novice. In the brief space remaining we can indicate only a few of the high spots which mark the type of transformation which comes as a result of practice or training. The rate at which an observer can develop this skill varies, of course, with natural aptitude and with his zeal or interest and willingness to follow the instruction given him. But like any other habit, such skill can only be learned through the expenditure, under proper conditions, of effort and can never be taught. All we are able to do in teaching an individual to acquire skill in seeing is to arrange the conditions as properly as we know for him, through his successive experiences, to teach himself. Just as in perfecting the golf stroke we hit upon more or less blindly the proper movements for the execution of the smooth, ballistic, efficient stroke, so it is in the case of visual perception. When the conditions are right, improvement comes often with sudden spurts, and often times in a wholly unpredictable way. In serving as a subject for one of my students I was able to reduce the time required to memorize a 12-digit number from about 25 seconds to about 1.5 seconds in three weeks, or in about 12 thirty-minute practice sessions. Toward the end of this period, I suddenly became aware of the fact that whereas I had started to perceive and memorize the 12 digits, reading them from left to right as four groups of 3 digits, I one day discovered that I was greatly reducing the exposure time necessary and unconsciously I had shifted to the plan of grouping by sixes; that is, a 12-digit number was seen as two 6-digit numbers side by side. The change in this case is not merely a change in the number of eye pauses, but it marks a step towards the complete reorganization of the visual perceptual process from an analytical, disjunctive act into one which more nearly represents the ultimate ideal of unitary, coherent grouping in which the 12-digit number is seen in perception as easily and simply as a number consisting of but two digits or even a

single digit. I tried to emphasize in a previous paper the importance of the recognition of the fact that all children previous to school experience perceive in this manner; that is, their perception is unitary, coherent and total. Educational methods usually proceed immediately to break this down and substitute for it specific and disjunctive process of analysis into parts which destroys individuality in the perceived content, and it is not at all unlikely that the early experiences of a child with reading, spelling and arithmetic do him far more harm psychologically than good. It is a debatable question whether the ideal schools of the future will not wait until the child is psychologically ready to learn these things, because it has been shown, for example, that fractions which require long time and some trouble in the third grade can be mastered in a few weeks if the student is introduced to them two to three years later.

(To be continued next month)

Psychology of Vision

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OPTOMETRIC EXTENSION PROGRAM

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

TRAINING TO PERCEIVE
(Part I)

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When we set ourselves to training a person to perceive rapidly, we must recognize that we are undertaking the reshaping of his functional visual fields. As indicated in the last paper, parts of the material which fall in the periphery beyond the limits of the field of clear form still are important instruments in the dynamic organization of the perception of shape. We must approach the problem, therefore, by the use of very simple material so that in the first several sittings the subject demonstrates to himself that visual shapes can be seen quickly and easily and with no fear of failure or mistake. Careful verbal instructions as to how the subject shall arrange himself at the apparatus, and particularly <u>what he shall do in the fore-period</u>, that is, in getting ready for the exposure, is of the greatest importance. An observer must fixate and accommodate his eyes so that when the exposure comes, no accessory, adjustory movements of the eyes are necessary for the clear and sharp imaging on the retina of the visual impression. In addition to this, the subject must be made to realize that he must develop and maintain an <u>active</u> attitude. Seeing the material presented very much resembles the process of "reaching out and grasping the material with the hand." The eyes are in one sense a certain highly specialized type of prehensible organ. Experience has shown that it is wise not to interfere with or try to force a new and strange set of grouping habits on the observer in the early stages of training. If, for example, an observer groups digits by threes or fours, or even twos, we let him discover by gradually reducing the time of exposure that he must hurry in order to "take everything in." Suddenly he discovers that while the physical time remains constant, phenomenal time can be greatly increased by extending the limits of his groups. Training will reach its ultimate level whenever the subject thus can extend the amount of material which can be apprehended in a single, rapid exposure. Bennett this year, in our laboratory, trained several observers so that they could accurately reproduce 16- and 17- letter English words in exposures of 1/1000 of a second. In the first few sittings these same subjects could not successfully perceive simple 6-letter English words in the same time of exposure. A second important consideration which likewise the subject must learn for himself is to abandon all thought of utilizing short-cuts, royal roads to learning, etc., because such things prove in the end to be a hindrance rather than a help. Thus all accessory movements which are non-visual are dropped out as early as possible. Using so far as possible the demonstrational method, we arrange conditions so that the subject learns that while the visual impression is delivered to his eyes, lip movements, phonism, and all inhibiting related processes are reduced to a minimum or completely eliminated. If improvement is to be extensive and rapid, vision must be given a clear track. Now here is one of the most important considerations in the whole process. As soon as the subject learns to do this he is surprised at the rapidity with which his span increases. Both children and adults are able in a short time to raise their eyes from the tachistoscope, look at the distant wall, and <u>project</u> a primary memory image of what was exposed to them clearly on the wall surface. This image is not a positive visual after-image because it can be held for periods of time and without fading in an entirely different way than the positive or negative after-image as these are commonly known. Nor is it a case of eidetic imagery. Here we are dealing with the simplest instance of the memory trace. What happens is most likely that the visual impression leaves in the sensory-cerebro-motor mechanism an after-effect which can be reconstituted in the same identical fashion that any conditioned response is capable of being evoked. The principle involved is the principle of redintegration. When we put the question "what did you just see," the response is a reinstatement in

visual terms of the same focal process which was figural during the period of the visual impression. Like any other habit this function can be greatly increased by practice or training. Thus in teaching a child to spell English words, when he achieves the skill of redintegrating the visual impression which he clearly saw, and we show him a card containing the same word with some slight mis-spelling, the reaction "no, no, that wasn't it" is as certain as it is instantaneous.

Leuba* has shown that images behave in a fashion which enables us to regard them as conditioned sensations. To quote: "Our experiments indicate that after an inadequate stimulus has been presented a number of times, while an individual is experiencing such sensations, it will, by itself, automatically, and without the intervention of any conscious process, produce those sensations. An image can, therefore, be considered as a conditioned sensation."

In addition to the above facts, let us consider the following simple experiment made recently in our laboratory with college students as observers. A 5 x 8 card containing the following six consonants was shown for 1/40 of a second:

V M T J W L

At the conclusion of the first exposure, one subject wrote on a slip of paper V T M - J L. A second exposure for the same length of time was given and on another slip of paper the same subject wrote V M T - J L. A third exposure produced the reproduction V M T J - L; the fourth exposure V M T J L -. The fifth exposure gave V M T J H L; the sixth exposure V M T J W S, and the seventh exposure V M T J W L, which was perfect. If we carefully examine this rather long and slow process by which the observer is finally enabled to see and reproduce exactly the pattern of letters impressed on his retinas, we first become convinced that the process is a very complex one. Not until the sixth exposure does the letter W appear and although the letter L in the last position has been seen and correctly reproduced in four of the first five exposures, it immediately becomes wrongly reproduced in exposure number 6. Notice also that the first three letters are correctly reproduced from the third exposure on. Invariably the left-hand portion of the combination of letters, numbers, or other materials is stronger and less likely to error than the portion seen to the right. Miss Banner several years ago in our laboratory analyzed some ten thousand errors in the reproduction of tachistoscopically exposed figures, and she found that the probability of any figure being incorrectly reproduced varied directly with its position from left to right, the least chance of error being in the first position to the left and the probability of error steadily increasing in a straight-line relationship toward the right.

The mere fact that a combination of letters may be seen correctly does not preclude the possibility of their being disarranged in subsequent exposures. For example, the following six consonants were similarly exposed to the same subject referred to previously:

N C S X Z H

After 16 exposures not a single correct reproduction of this combination was attained. In the first exposure, the letters N C X H - were reproduced. In the second exposure N C S X H - was given. In the eighth exposure N C S X H - was given and in the next or ninth exposure, N S H J - -. Exposures 13, 14, and 15 were all seen identically as N C S X - H. No. 16 was reproduced as N C S H X -, which, it will be noted, is identical with the second reproduction. Further, it is noteworthy that the consonant Z in the second from the last position was not once seen and reproduced in any one of these sixteen exposures, each of 1/40 second duration. Many other interesting facts present themselves when we study carefully day after day the repeated experience of an observer being trained to perceive visually quickly and accurately. The only way I can clearly indicate this fact is to cite some actual illustrations. If we show five to eight digits in short exposures of 3 milliseconds, the digits are usually all correctly reproduced, but often in the wrong order. The content of perception thus comes earlier and is simpler than the achievement of the proper and correct arrangement of this content into exact visual forms which are replicas of the stimulus. For in-

*Journal Experimental Psychol., 1940, 26, 345-351.

stance, the number 720549 was shown, and the subject's reproduction was 754092. Here all the numbers are correctly reproduced but seriously disarranged. When 73584 was shown, the reproduction was 75384. This represents a simple inversion of the second and third digits. The subject s report I quote verbatim: "I was not so sure about the 8, which may have been in the third position; I am quite sure of the numbers 753." We have literally thousands of instances of this fact, that the feeling of certainty usually comes <u>after</u> the subject has made his verbal or other motor reproduction of what he has seen, and the chances are about even that this feeling of certainty may accompany an erroneous reproduction of the stimulus or a true one.

(To be continued next month).

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

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OPTOMETRIC EXTENSION PROGRAM

TRAINING TO PERCEIVE
Part II

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The subject does much better if he is set to see a specified number of digits. If we have been showing him in brief exposures six digits and we suddenly expose a card containing eight digits, the subject will almost invariably report that all the digits appear blurred. The end ones are sometimes seen clearly, but the ones intermediate seem to manifest a curious instability often described as not stationary, blurred, like they were in motion. We have reached the conclusion from many such observations that an essential part of the perceptual act is not only under way but may be virtually completed before the stimulus is presented to the eyes. If an error is made in reproducing a number, re-exposure is likely to result in a repetition of the erroneous digits in the same form. This may occur several times during a day's sitting or it may even bridge several days. For example, from the protocol book before me, I note that on May 24, 1940, the following digits were exposed for 3 ms. to a subject: 715206. This number was reproduced as 712605, with the subject reporting that he was not sure of the last two digits. Immediately following this, the number 513904 was exposed and correctly reproduced, after which the number 261047 was exposed and reproduced as 264017. Then followed a repetition of the number 715206 which was reproduced 715605, and after three subsequent re-exposures during the same half-hour of this same number, all three of these exposures were reported as 715605. Another exposure was given to another subject as follows: 703158 was shown and this was reproduced as 703518. After two other six-place numbers were exhibited, 703158 was re-exposed and again reproduced as 703518. Now the same card was immediately re-exposed, and the subject correctly reproduced the number 703158, reporting that "this number was the same as the one previous; I had inverted the last part of it."

Grouping always undergoes a series of interesting and important modifications in the course of training. After eight digits are shown, at first they may be seen as two groups of three plus two digits. After several days the subjects begin seeing them simply as two groups of four or as 3-2-3 or finally as a single aggregate of eight digits, without the psychological separation which marks group boundaries. McIntyre has studied this problem of grouping in our laboratory with some very interesting observations. If a number is grouped in threes, an inversion of the third and fourth digits, counting from the right, is never observed although inversions may occur frequently within individual groups. Experimental attempts to force regrouping were made in the following manner: suppose nine digits are shown to an observer who sees them as three groups of three. Suppose further that on this card we print the first two digits from the left in black, the next two in red, the next two in black and so on; remember that on the card all digits are printed with no unusual spacing. Mr. McIntyre observed that no color at all was noted and nothing strange or unusual reported by the observers for several days. The grouping by threes continued, thus indicating that where the subjects were set to see visual forms, such secondary attributes as the color of the digits completely failed to register. Artists report similarly, that they do not see form and color simultaneously.

The advantage of using rapid exposures is, of course, that it enforces upon the subject the necessity for actively grasping the material during the brief compass of the exposure. If he learns, he unconsciously adopts larger grouping units. This process becomes equivalent to increasing the time of exposure. Schwarzbek found that if his subjects, in this same type of experiment, had reached a place where they seemed to make little, if any, improvement, that after he suddenly increased the number of digits keeping the time of exposure constant for a few trials, then returned to the original number, improvement sometimes came with

striking rapidity. Whatever the mechanism of the schemata or perceptual frames of reference in the visual perception of symbolic forms, it is certain that the eventual attainment of high degrees of skill must involve a reorganization along lines of greater efficiency of this mechanism, and that this is done by the subject unconsciously as a by-product of effortful practice. After working at this problem more or less continuously for the past seven years, we feel that the precise description and control of the process of perceiving visual forms is only partly and incompletely understood at present, and that much further work must be done before the most effective methods of teaching children and adults to see written or printed symbols rapidly and effectively can be specified. In our work generally we prefer to follow a work-limit method; that is, a method in which the length of material is kept constant and the time of exposure gradually reduced until the tolerable limit is reached. Roelfs has recently printed an article in one of the German journals in which he has considered the question as to what is the actual time involved in a simple act of perception. His conclusion is that it is extremely short, so short in fact, as to be practically immeasurable. It might be well to add that perception is largely an all-or-none process. The examples I have cited above show that repeated exposure is not enough to correct an erroneous first impression; whereas, if the same material is exposed to another individual who sees and reproduces it perfectly, he always has the impression that the time of exposure was plenty long and that the whole process ran off with lightening-like rapidity. Just as important as the fore-period, and the actual stimulus-impression period, it is necessary to give careful attention to what we have called the post-impression period, because we have found that upon the cessation of the stimulus many things can happen to invalidate the reproduction of the exposure. A trained subject may wait from five to twenty seconds before he begins verbally to call out the digits exposed to him. During this time the subject will describe his experience as waiting for the proper moment to begin. This comes with a feeling analagous to the operation of a determining tendency, common in the experience of all of us. As an example, if I am asked to purchase some small article on my next trip down town and after transacting my own business I step into my car and prepare to return home, I may be plagued with a vague feeling that I want to do something which I have not done, but for the life of me I am unable to recall what it is. The sight of the front door or my wife may be sufficient to re-instate the whole matter. In post-hypnotic suggestion, the delayed action of an impulse to react is well-known and easily exhibited. Something analagous to these instances closely resembles the type of thing in the post-impression period. The numbers seem to com out of nowhere. They come with an assurance, although the feeling of assurance is not a safe guide to their accuracy. I have seen it happen again and again that a singl digit may be omitted from a number containing, say, ten digits. The subject may recall nine correctly. If now we say to him, "guess," as to the missing digit, we find that about eight times in ten he will guess the correct number. There are many reasons for believing that the sensory impression is never complete until the act of motor reproduction has thus formed itself, and has been given expression.

Along with the willingness of the subject to co-operate and try hard we find that the feeling of success as achievement improves is a conspicuous factor in promoting still further success through training. It is always important to keep the learner informed of his stage of progress and to keep clearly before him the goal toward which you are striving. This goal which seems utterly unattainable in the earliest stages of practice comes closer and closer as he realizes his own achievement. Difficulty and uncertainty disappear and I am inclined to think that the strictly sensory characteristics of the impression gradually diminish in importance as the subject develops higher and higher degrees of perceptual skill. This is a problem of great importance for all orthoptic training, and so far as I am aware very little is known about it at the present time.

It is impossible in the limited space at our disposal here to give more than a very sketchy account of the rather large amount of experimental results we have secured in several years of work upon the general problem of the visual perception of form. It is possible that this series of papers may continue during the coming year. I

have had a few letters expressing interest in the series and appreciation of it. I want to take this means of thanking these good people and to say that this is the only way we have of knowing whether these more or less informal talks are fulfilling the purpose for which the Extension Program intends them. It would be very helpful to receive as many favorable and unfavorable criticisms and suggestions as possible. Thus, if the papers are to continue another year, we would be in a better position to outline a series better organized than those just completed. Any suggestions addressed to me, Department of Psychology, The Ohio State University, Columbus, Ohio, will be deeply appreciated. If, in the present year, you have been lead to see that psychological optics is capable of producing important contributions to the science of seeing, then well begun is half done.

- Samuel Renshaw

Psychology of Vision

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

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OPTOMETRIC EXTENSION PROGRAM

A SUMMARY OF THE 1939-40 PAPERS ON THE PSYCHOLOGY OF VISION

October - 1940 Vol. 2 No. 1

At the California State Meeting in August 1940 at San Francisco it was requested that a summary of the twelve papers in the series on Psychology be prepared for October. To condense something which is already abbreviated is never an easy task. Particularly is this true when the author is troubled by the sprectre of all the problems, facts, theories, experiments, etc. which were not and could not be included in that brief series. Any further boiling down can therefore be little more than a grouping of some generalizations and an indication of what is to be found from a careful re-reading of the whole series. The Roman numerals will indicate the numbers of the papers.

The original writing of the 1939-40 series of papers on vision was undertaken at the request of Drs. Alexander and Skeffington because they believed they saw in the developments from the laboratories of experimental psychology some things of interest and importance for optometric theory and practice. I agreed to undertake the assignment in the hope that the important but neglected province of psychological optics could be brought to the attention of leading optometrists. It is to be hoped that critics of the series will bear in mind that the entire series must be regarded as only an abbreviated sample. A full exposition of the problem of visual perception alone would consume a volume of sizeable proportions. The object was to give a start and a direction to thinking in a province which is generally neglected in optometric education, and yet which plays a role of the first order importance in every eye examination.

In 1709 Bishop Berkeley wrote his famous "Essay Toward a New Theory of Vision". In it he raised questions as to how we are able to perceive the size, distance, position and shape of objects. After a remarkable summary of facts and arguments he concluded that none of the above properties of things is given by vision alone, but only by vision in cooperation with the sensations of touch, pressure and movement. Not until visual impressions are translated in terms of touch and muscular movement do these impressions become spatial. And so long as they remain non-spatial they may be regarded as essentially non-existent. Thus psychology has its own vested interest in the most fundamental of all visual problems.

But verification was needed for Berkeley's theory. Soon various physicians began to contribute to the Transactions of the Royal Society of London the results of observations on persons operated for congenital cataract. One of the most famous of these was the case reported by Cheselden in 1728. This was followed by Home, Ware, Wardrop and others. Persons suddenly gaining sight for the first time should not be able to see form, size, position, distance, etc. In general, the evidence was fairly uniform: the patients could not recognize objects by sight alone. Cheselden's patient, on seeing a familiar cat, could not tell what it was. Home's patient thought a number of square and oblong cards were round. Raehlmann's patient, when shown a large bottle, said it might be a horse! Trinchinetti's young boy and girl grasped at things as if they expected to find them in the neighborhood of their eyes. Visual properties were not visual natively. They were products of learning.

The modern case of George Campbell, the Oklahoma boy, studied by Drs. Alexander, Skeffington and Thoma gives verification, as many of you have heard from Mr. Campbell in person, to the proposition that even with relatively perfect vision people have to learn to see.

Berkeley's theory, or the more modern variants of it, have been disputed by many competent scholars. In the main they hold that the discriminations of shape, form,

position, movement, brightness, hue, etc., are far more complex problems than the simple "solution" offered by Berkeley suggests. Even though a strong case can be made for this latter position, nevertheless one thing is clear. Both views present the strongest argument in justification of the objective of our series of papers. Optometrists can not afford to disregard what psychological optics has to offer, both in past accomplishments and more strongly in what the future promises.

My own view is that psychological optics will reshape the whole trend of professional optometry. These matters are intimately bound with the very definition of optometry.

It has been stated that "only seven percent of all the cases presenting themselves to the optometrists offices have any disease complication."*

If this is a true estimate then the 93 percent constitute problems in a distinctive field - Optometry - and in this field experimental psychology will continue to make helpful contributions.

I.

The understanding and control of vision comes through several divisions of science: anatomy, neurology, physiology, biochemistry, physics, mathematics, etc. To these should be added psychological optics for reasons indicated above. Much of seeing is not done with the eyes. Our total discrimination, as for example in reading, is partly aural and motor. No sense organ works or exists in isolation. The trend is toward the unity of "the senses". Analysis of simple instances of seeing shows that we refer objects to positions external to the body and that our space and form frameworks are shaped and transformed by learning. Even simple things seen are not direct copies (retinal images) because if they were life would be a hopeless confusion A book is only rectangular visually when it is in a relatively narrow field. In perception there is also always a suppression of some details and an enhancement of others, so that what we see is rarely if ever what is exactly out there, but rather our own interpretation of it. Every visual instance involves important and far reaching psychological considerations.

II.

As in the first paper we sought a justification for psychology in optometric thinking, in this next paper we try to lay emphasis upon the great necessity of carefully scrutinizing the fundamental point of view.

The sciences emerged from ignorance and superstition by expanding basic concepts and refining methods. The biological groups, younger than the physical sciences have made particularly great progress in the past half century. This has been largely due to a broadening of theory and to the consequent stimulus this gives to the experimentation which opens up and consolidates new fields. The organismal theory and the cell theory are cited as examples of the molar and the molecular ways or regarding, analyzing and describing processes in living things. Have we failed to make greater progress in vision because we have looked for the answers in the wrong places? Differences in schools of thought in optometry as in any field are a sign of healthy growth. But this health can only be maintained by the frequent and careful overhauling of your fundamental concepts of theory and practice.

III.

The first half of this paper continues and extends the argument on point of view and attempts to show how modern experimental psychology has changed its problems, methods and theoretical interpretations as it has matured. The molecular analysis of mind into elementary sensations, images and feelings, held together by a mythical associative force, has practically been abandoned because it proved to be unproductive. Action and the motor aspects of experience, without which the sensory ceases to exist, was minimized or totally neglected. To illustrate the modern trend which has come to replace the older ways of thinking, first some facts relative to the response of the eye to light stimulation are given, and this if followed by,

* Brucker, The Story of Optometry, Minneapolis, 1939, p. 15.

IV.

which presents facts relative to the relation of light intensity and size of pupillary opening, particularly in dark adaptation; changes in retinal sensitivity with change from photopic to scopotic vision (Purkinje effect); the stimulus thresholds for brightness; Fechner's law; the visibility curve and its characteristics, and duplicity theories. The object in this paper was to present some of the well established facts of the eye in its response to light, to pave the way for

V.

in which seeing as a habit is discussed. Some simple photometric experiments were described to show that the response to continuous increments in stimulus intensity is a discriminally discontinuous function. There is no one-to-one correspondence between the characteristics of the stimulus and of the resulting discrimination. We never see exactly what is presented to the eyes. The eye, as is every sense organ, a compensatory device. In pattern vision the energy pattern is transformed at the retina and in the central nervous mechanisms. The effectors impose back upon the system limitations which indicate that the determination of either form or intensity of response is not centrally controlled. Sensory processes can be and are transformed by the resulting executant motor processes. The primary function of the sense organs is to start movements of approximation and correction of an adjustory or adaptive character. What we see becomes defined largely in terms of our own particular responses to the visual signal pattern. Perceiving is a search for meaning. It always involves in one form or other tentative, searching or anticipatory movements. Seeing, like any other skill, is essentially a habit and is susceptible to large practice effects. The importance of etiology in optometric practice is therefore strongly indicated.

VI.

Seeing as Visual Perception. The facts of memory indicate, among other things, that no one ever "sees a retinal image". The perceived pattern is far too complex for so simple an "explanation." Perception is described as a dynamic process of figure-ground structuring. The properties of the figure portion of the visual field differ from those which constitute the ground. Some experiments by leading investigators in this field are cited. Sensory components are only partly responsible for the course and the end product in any act of seeing. Perceiving is essentially a non-sensory function. This paper should be carefully re-read.

VII.

This paper continues the previous one and the genetic relations of perception and the development of language are discussed. The space discriminations of the skin are examined because they are more primitive than those of vision and we can see many things in simplification in them which apply also to vision. A series of experiments were described in which congenitally blind children and adults were compared with seeing children and adults with respect to the accuracy of localization and effects of practice upon the localizing function. The apparent large differences between children and adults, in favor of children, and in the case of the blind and seeing, reduce almost wholly to the influence of vision upon the localizing function, for points stimulated on the cutaneous surface. The space of the skin depends upon vision just as the space of vision is inextricably interwoven with other sense modalities.

VIII.

This paper begins with a summary of some of the facts as to the emergence of figure from ground in perception, then describes a special instrument, a tachistoscope, for studying this process in brief exposures. In a world record performance numbers containing 8 digits were perceived in .003 sec. and later reproduced. 10 digits took .264 sec. 12 digits took an exposure of .824 sec. but was finally reduced by another subject to .711 sec. Aside from the speeds involved the fact was brought out that ordinary college students could be and were trained to do comparable feats. The analysis of the methods used by the perceiver as a novice and after training developed certain facts of importance in training children to spell accurately and to read fluently and comprehensively. To do so one must perceive coherently,

unitarily rather than disjunctively. The whole process is very complex and comparatively little is known about it at present although progress is being made.

IX.

Reading is considered as a special case of perception. Language is the most complex coordination made by any living creature. It is a surrogate or substitute mechanism. Comprehension develops much earlier in children than does skill in linguistic expression. Children early perceive unitarily. Often learning to read makes them disjunctive perceivers and they become "problems". Bad spellers and poor readers show poor methods of perceiving. In most instances they do not see the printed symbols or see them erroneously. Re-exposure does not correct the initial error. Seeing form is a very involved process. Some experiments and the methods used in studying these problems are described. The process of perceiving correctly and quickly is very susceptible to training, provided appropriate methods are employed. Eye movements are consequence rather than a cause of poor reading.

X.

Perceptual filling and a number of studies on visual perception in short exposures of digits, consonants and English words was presented, giving further description of the process of visual perception. Important in securing improvement are such things as the control of the learner's attitude, method of attack, the number, length and distribution of the practices, manner of grouping, set, etc. The motor aspect of the process of perceiving was strongly emphasized.

XI and XII.

These two final papers present a short description of actual experiments in training individuals to perceive more rapidly and accurately. In the first paper what the observer does before, during and after the exposure is described. Content is perceived correctly earlier than form. The persistence of certain types of errors upon repeated exposures indicates that more sensory impression alone is not a sufficient corrective. The set of the observer is important in establishing the frame or pattern of the percept. Short exposure tends to force unitary or coherent seeing. The trained subject does something different from the novice, something which closely resembles the change in any skillful act from the early jerky phasic movements to those of ballistic form. The limits of improvability of the perceptual function are unknown at present but they are so great as to challenge credulity. Seven years of research upon the problem cannot be readily condensed into a few paragraphs. All indications point to a rich and fruitful future for the orthoptics side of optometric practice. But this can only come with close cooperation of the laboratory researcher and the practitioner.

Psychology of Vision

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OPTOMETRIC EXTENSION PROGRAM

by Samuel Renshaw, M. A., Ph. D.
Ohio State University

PSYCHOLOGICAL OPTICS

November - 1940 Vol. 2 No. 2

Illusions

During the past summer a change of plan was made concerning the content of this series of papers. This change was made following suggestions from well known persons in optometry. It was decided to present a series of rather simple experimental demonstrations which the readers of these papers can make in their own offices. Each month we shall present one or more of these experiments or demonstrations described as to procedure and as to the needed equipment. It is intended that the reader will 'work with his hands' in making these demonstrations. After making the observations consider the principles involved and the ways in which use can be made of the materials either in the present form or in some modified forms in daily practice. We hope it will be found possible for many optometrists to utilize some of these things in practice. Some of them may be discovered to be applicable in diagnosis and in visual training or retraining.

The construction and assembly of details will be simple, so that no particular difficulty will be experienced. The materials in most instances will be found readily available at the stationers, the dime store, or perhaps in the office.

We propose to have you demonstrate to yourself a number of phenomena of psychological optics which will prove both interesting and instructive. We want you to catch something of the spirit of investigation by the first hand experience of doing these experiments and interpreting them for yourself. When you develop some interesting variation, use, or interpretation, we suggest that you write us about it so that we may serve as a sort of clearing house for these ideas. We may even look forward to a time when highly valuable facts may be formulated by men in different sections of the country pooling their efforts and observations according to some carefully made plan.

For those who wish to go a little more deeply into any problem in the series we shall suggest a number of references for further reading.

Supplementing this first paper is the first of four parts of an extensive discussion by Dr. McFadden of the basic problem of Visual Acuity and its Measurement. Taken together these four papers will give you a valuable summary of the theory, previous experiments and literature on the problems relating to the concept of acuity, together with a summary of Dr. McFadden's own research contributions to this problem.

With regard to the demonstrations, it is our purpose to suggest to you some problems and questions relating to the demonstrations which should be taken up and freely discussed in your group meetings. Particular emphasis should be placed upon two things: first, clear understanding of the principles in psychological optics involved; and second, in identification of those places in your thinking and practice where these principles and demonstrations may be put to practice. In the laboratory we are bound to see these phenomena in a different light from those of you engaged in daily clinical practice. From time to time we shall suggest certain possibilities along the above lines. The discovery of the uses and applications must, however, be left largely to your own ingenuity and cleverness.

Someone has paraphrased the proverb to read "Seeing is deceiving." In the perception of lines, forms and movements of objects in space we commonly experience distortion or deviation from "reality" in our interpretations of these things. One classification of such phenomena names them illusions. But what is an illusion?

Here at once we encounter a most interesting and difficult problem. If we seek for a dictionary definition of the term "illusion," we customarily meet with the statement that it is a misinterpretation or a false perception of some class of observa-

tions or processes experienced. The chief difficulty with such definitions is that they do not define because it is impossible to establish on any scientific footing a concept that an illusory experience is necessarily false. Nor is it possible to establish the fact that it is a misinterpretation, since we shall presently show you types of visual illusions which fail to meet such stipulations.

It is suggested that you try to formulate for yourself a definite and comprehensive statement as to what constitutes an illusion. Try to make your formulation precise and limited so that it includes only those phenomena which may be truly classed as illusions.

In the series of papers during the past year some pains were taken to discuss the characteristics of visual perception for several classes of objects. It might be profitable to reread these sections particularly with respect to the concept that everything we perceive assumes the form of a figure upon the ground. It should be borne clearly in mind that part of the ground in any perceptual experience is the perceiver's own frames of reference. Whenever a figural experience is set in an inappropriate ground the resulting interpretation is most likely to be in error. The qualitative and quantitative nature of the resulting interpretation may therefore depend upon a considerable number of factors, part of which are characteristic of the stimulus figure and its relations and part of which may derive from the set, attitude, expectancy or self-imposed instruction contributed by the perceiver himself. We have pointed out in the past that many phases of our visual perceptions of form, position, size, movement, and similar properties of things are susceptible to practice effects and are intimately related to the motor aspect of experience. What we do with any object or what it does to us becomes largely instrumental in recasting the form of our perception and interpretation of that objec Even the anatomical and neurological structure of the visual end organ demands that objects in different spatial positions can not be uniformly and isomorphically projected upon the sensative surface of the retina We must consider the retina as a first zone for transformation of things seen.

Care should be taken with respect to the normative phase of the problem of illusion. There are undoubtedly as many visually experienced distortions of space and form which are perfectly normal, conventional, every-day experiences as there are which may be classified as abnormal, erroneous or unnatural. It is for this reason that we must exercise considerable care in the theoretical formulation of our concept of illusion in order to bring it into accord with the fundamental theory of perception. Let us look at a few examples of visual space illusions.

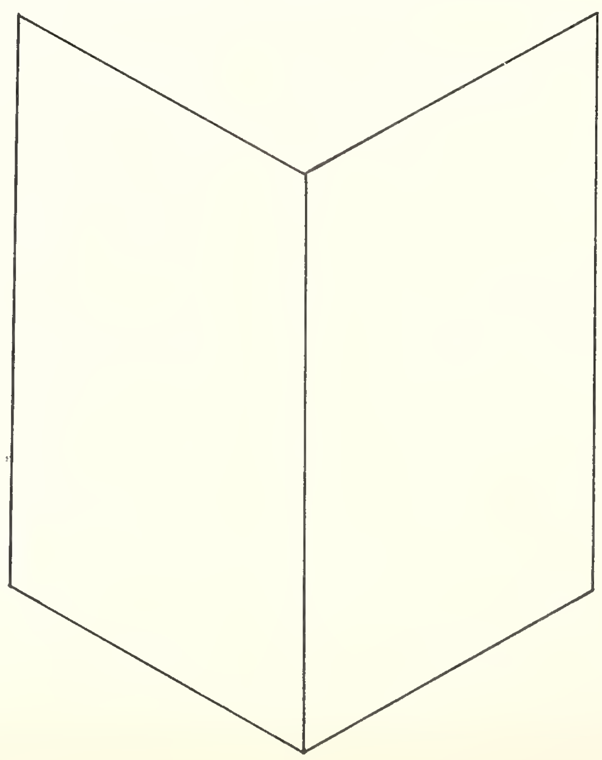


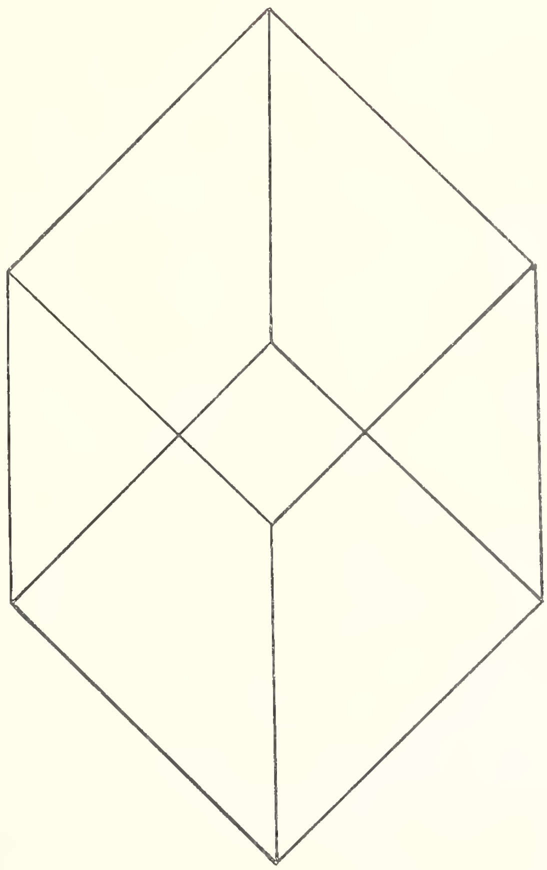
Fig. 1

Note carefully Figure 1 which is known as Mach's book. As you look at this figure it may be seen either as a book opened toward or away from you. If your fixation is on the middle vertical line the book seems to be opened away from you. If either of the other two vertical lines is fixated, the book immediately is seen in a new orientation, that is, toward you. This constitutes one of the simplest illusions of reversible perspective. The facility or nimbleness of one's vision may be indicated by the rapidity or number of times per minute one is able to change by shifting the point of regard the perceptual orientation of this figure. It would be interesting to try timing a few patients with different types of cases to note variations amongst them in this respect.

Try the figure both in the vertical and horizontal orientation. Try it both monocularly and binocularly.

It should be noted that in simple illusions of reversible perspective of this type we are dealing with one of the most elementary considerations in seen movement, namely, change of position in space resulting in change of point of regard in a bi-dimensional figure which does not move. Further, it should be noted that we are dealing with one of the simplest and most fundamental considerations in stereoscopic vision. The two dimensional figure takes on third dimensional or depth properties when the observer himself does something, and this change occurs equally well whether the figure is viewed binocularly or monocularly. It might be interesting to view the figure through slight fogging lenses and to time the reversals when the figure is reduced in size by the use of appropriate lenses.

Fig. 2



This figure is known as Necker's cube. Look at the figure and regard it as a series of diamonds, triangles and squares laid upon a flat surface. See if you can voluntarily suppress for any length of time its tridimensional property. Determine what change in fixation precedes or accompanies the transition in perspective as the cube becomes a solid figure and record the number of positions the solid figure can take.

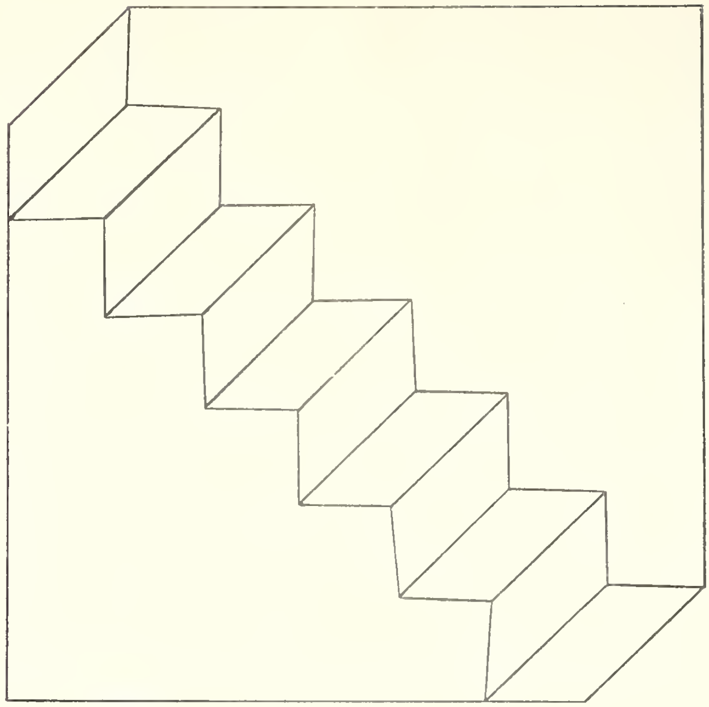


Fig. 3

This figure is known as Schroder's stair figure. Note that if the proximal lines determining the near ends of the steps are fixated the figure is seen as a series of stair steps. If the distal lines are fixated, it immediately becomes a cornice, or if the central lines are fixated the same result follows. Record the average number of voluntary reversals you can make in one minute and compare this number with that secured in Fig. 1. Does the degree of complication of the figure influence the rate of voluntary reversal?

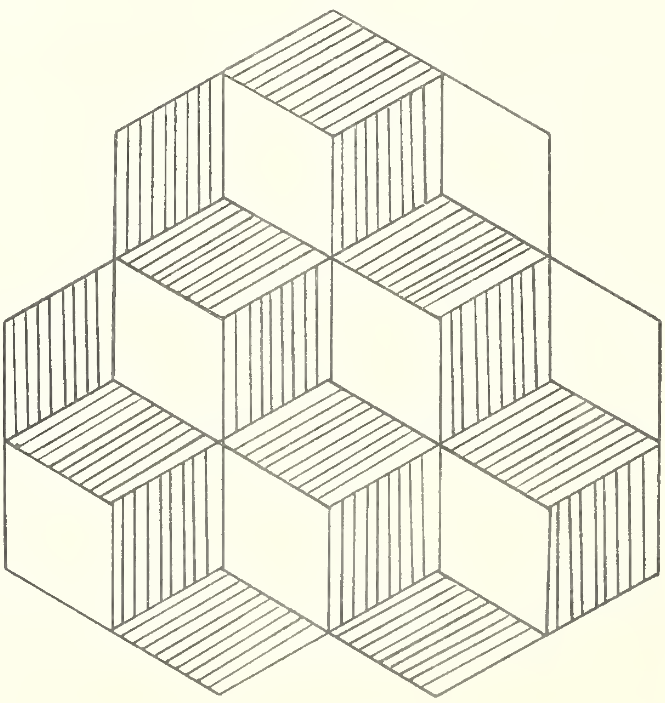


Fig. 4

This figure provides a further illustration of the well known illusion of reversible perspective. Its usual title is "How many cubes"? It will immediately be seen that whether 6 or 7 cubes are seen will depend upon the phase of reversal of the figure.

Fig. 5

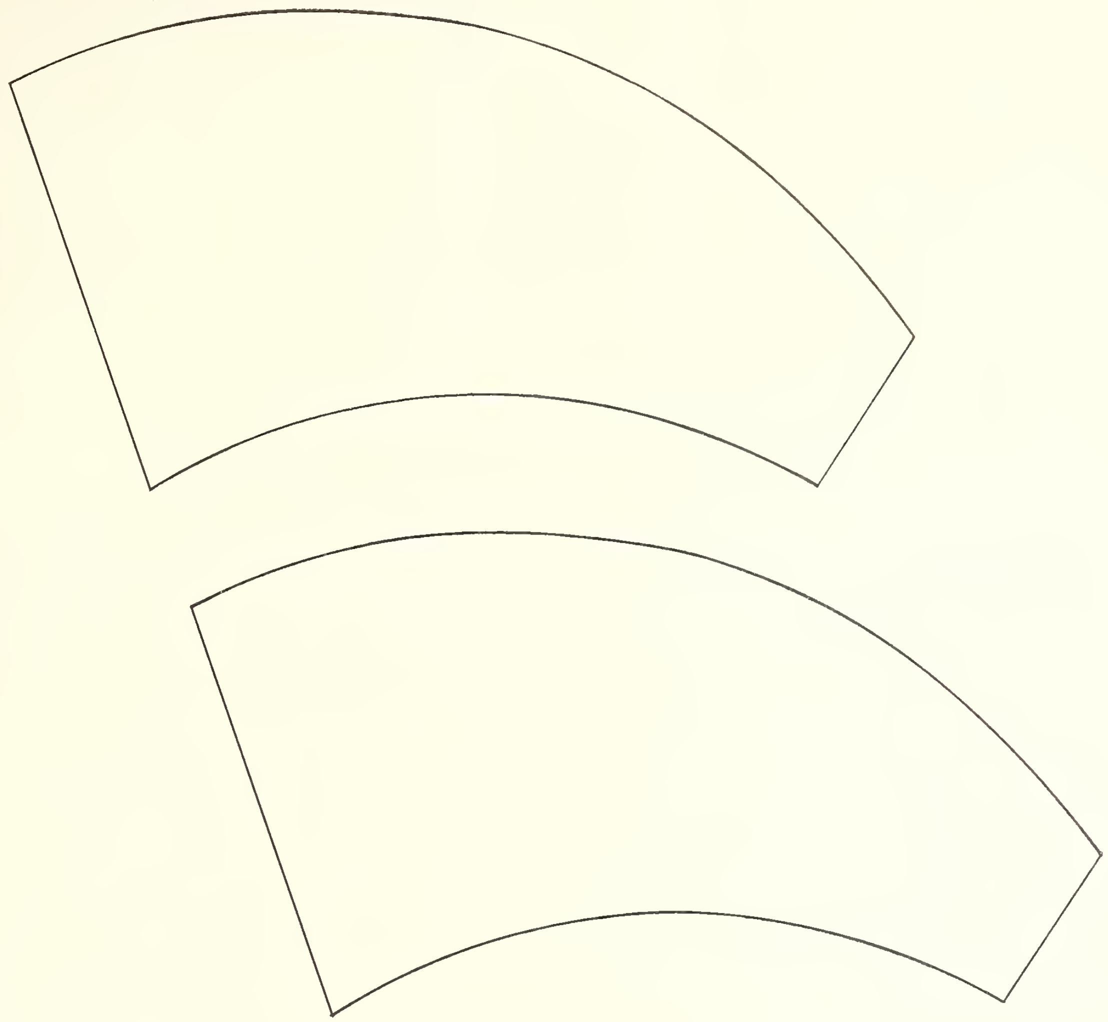


Figure 5 is the well known Jastrow illusion. From a piece of stiff white card board, prepare four pieces twice the size of those used in the illustration. Arrange them as in the above figure except that the additional two are to be placed above the positions shown in Fig. 5. Examine them carefully and note that the top figure gradually diminishes in apparent size and the illusion persists regardless of change in fixation. This can be demonstrated by removing the bottom figure and placing it at the top. In this instance the position of any of these figures with respect to its neighbors is a decisive factor in determining its apparent size. A method could be devised for measuring accurately the reduction in size occasioned by the relative position of any one of these figures. It might be interesting and instructive to work out the details of such a method and take a series of measurements comparing, for instance, the responses of young children and adults to this illusion. Such results should throw light on the experience theory of perception or the problem of nativism vs. empiricism. In other words, if the illusory effect is a product of experience then we should expect the younger subjects to show less measurable effect of change in relative position.

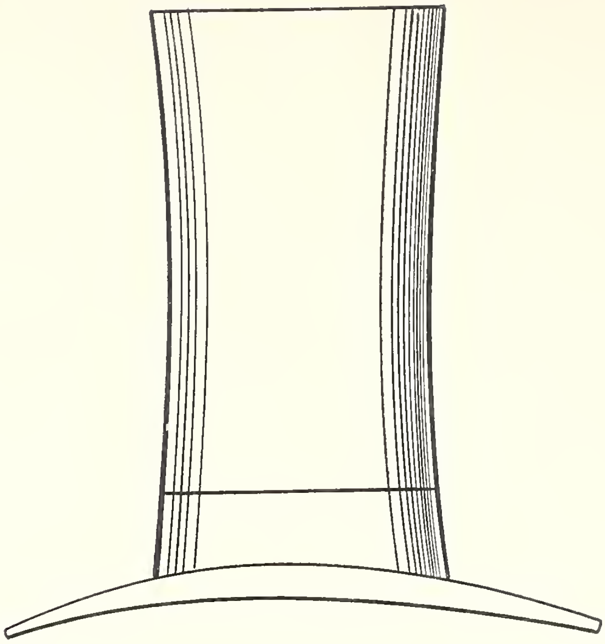


Fig. 6

This might be called the "high hat" illusion. It is introduced to illustrate a further phase of relative position in space. How does the horizontal width of the rim of the hat compare to its heighth? Although the two dimensions are equal the vertical component is overestimated.

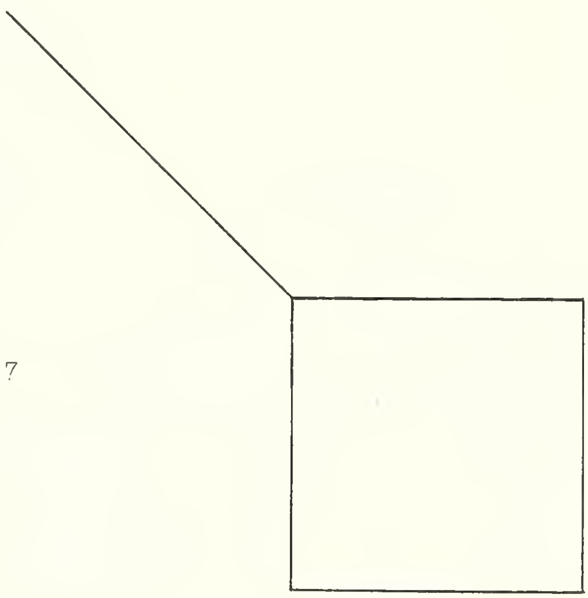
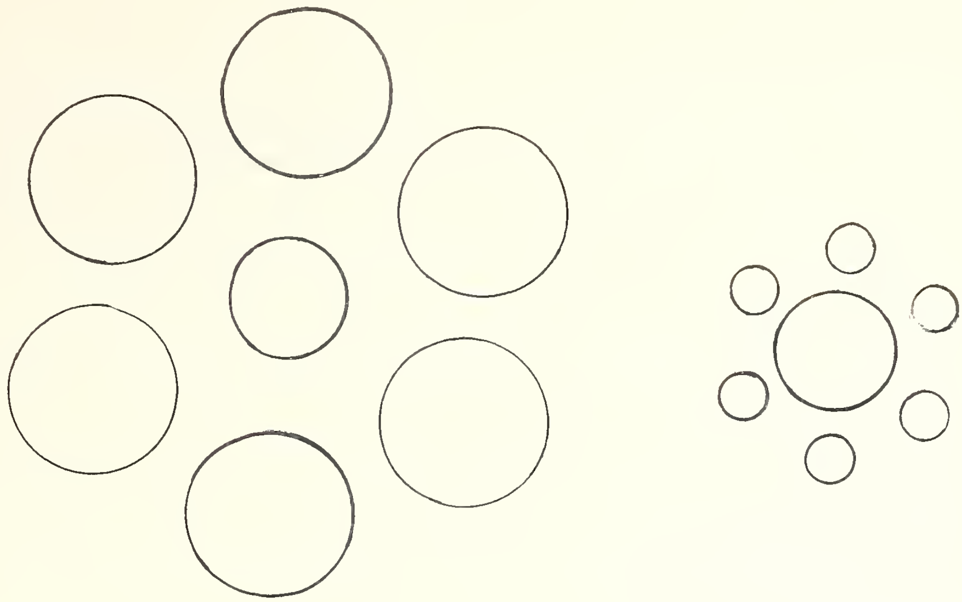


Fig. 7

This figure represents a whole class of illusory experiences which are usually characterized as filled vs. unfilled space. The problem is to compare the length of the diagonal line representing the lid with the diagonal of the square representing the box. If the hinged lid were rotated until its distal end meets the opposite corner of the box, namely, the lower right hand corner, will it fall short or coincide or extend beyond the limits of the square? Here, again, a mechanical model could be made and measurements taken to indicate the extent of the illusion.

Fig. 8



This figure is known as Ebbinghaus' circles. It represents a class of illusions in which the size of the figure is influenced by the ground in which it is set. The problem is to compare the relative sizes of the inner circles surrounded respectively by larger and smaller circles. The diameters of the inner circles are the same.

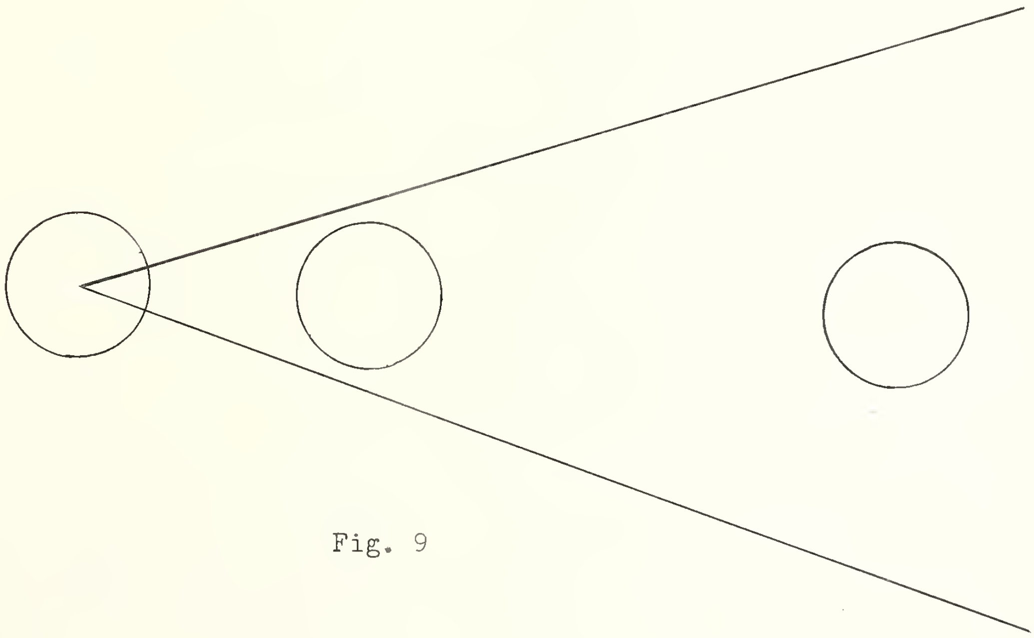


Fig. 9

Figure 9 illustrates the change in the relative sizes of the two circles enclosed within the angle. Both Figs. 8 and 9 illustrate the fact that our judgments of the size of any object are largely dependent on the surrounds of that object.

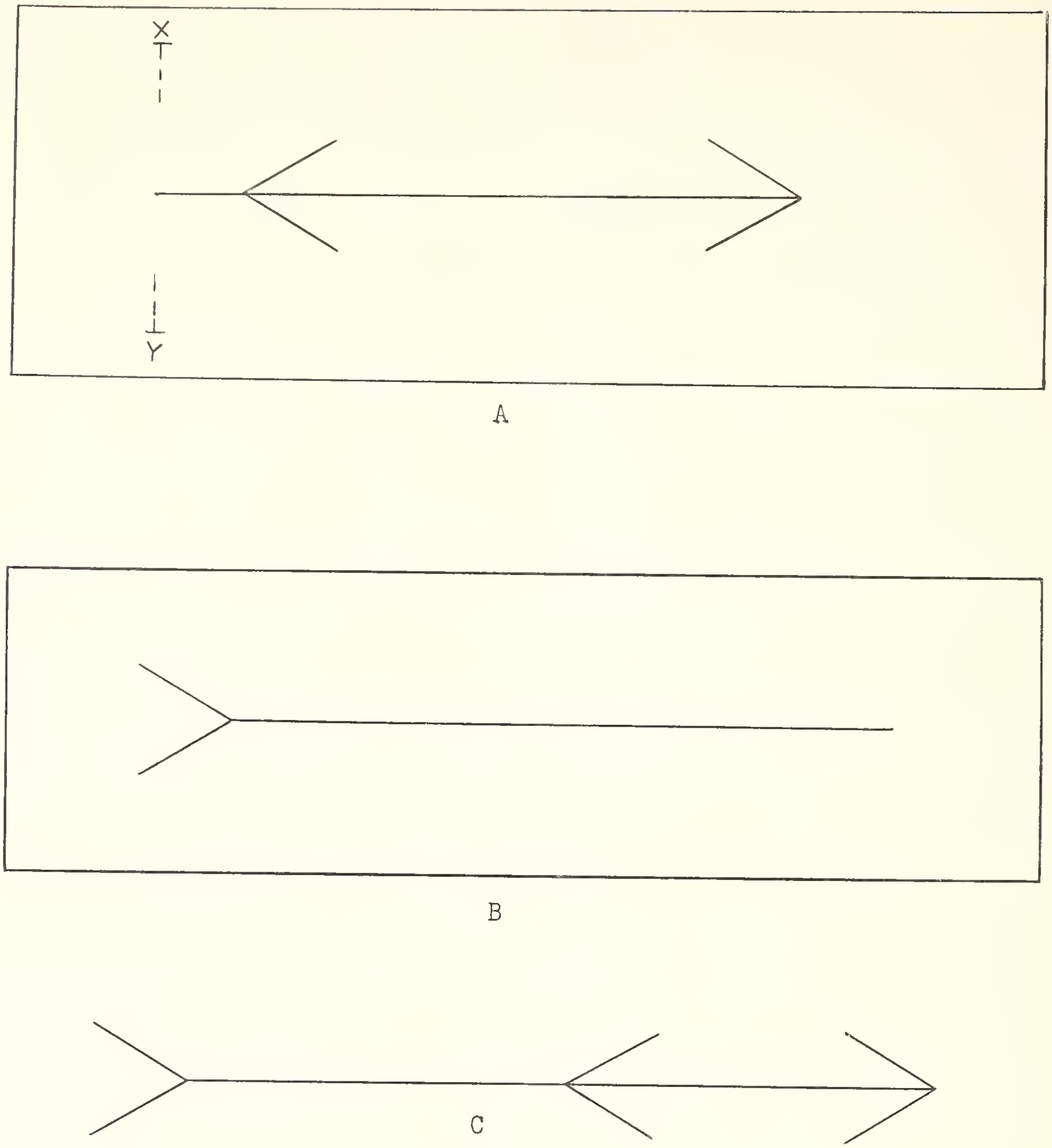


Fig. 10

One of the most widely known visual space illusions is known as the Muller-Lyer figure. There are numerous variants of the principle exhibited by this figure. The problem is to judge the relative lengths of the horizontal lines between the arrowheads. The following instructions will tell you how to construct this figure so that it may be made adjustable and exact measurements of the extent of illusion determined in any orientation in space. It is suggested that you try it on yourself. Find the average of ten determinations when the figure is seen in the horizontal, and of an equal number in the vertical orientation. It is further suggested that the figure be viewed first at one meter, then at three meters, and the influence of visual angle upon the size of the error thus determined. It may interest you to know that no fewer than a dozen theories have been proposed to account for this illusion. These may be found in Titchener, E.B., Experimental Psychology, Instructor's Manual, Qualitative, 321-328 inclusive.

From a piece of white cardboard prepare parts A and B of Fig. 10. The piece on which A is to be drawn should be about 10 by 30 centimeters. Make the distance between the arrowheads 20 centimeters. Draw the arrowheads at 30 degrees from the horizontal. The lines should be approximatel 3 millimeters thick. Cut a slit from X tc Y and insert B so that the total appearanc will be like that of C in Fig. 10. This will provide you with an adjustable Muller Lyer figure.

There are scores of other forms of visual illusions. The above examples may be sufficient to give you a start toward the problem. Some references follow:

REFERENCES

1. Titchener, E. B., Experimental Psychology, Student's and Instructor's Manuals, Qualitative. McMillan, New York, 1905.

2. Luckiesh, M., Visual Illusions, Their Causes, Characteristics and Applications. Van Nostrand, New York, 1922.

3. Wallin, J. E. W., Optical Illusions of Reversible Perspective. Privately printed, Princeton, N. J., 1905.

4. Woodworth, R. S., Experimental Psychology. Holt, New York, 1938.

5. Koffka, Kurt. The Principles of Gestalt Psychology. Harcourt-Brace, New York, 1935.

6. Ellis, W. D., Source Book of Gestalt Psychology. Harcourt-Brace, New York, 1938.

7. Troland, L. T., The Principles of Psychophysiology, 3 Vol. Van Nostrand, New York, 1930.

emonstrations in
Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

RETINAL OR BINOCULAR RIVALRY

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Samuel Renshaw, Ph.D., Ohio State University
with the assistance of Hugh B. McFadden, Ph.D.,
Graduate Clinic Foundation and O.E.P. Fellow in Experimental Psychology,
Ohio State University.

Many interesting experiments grow out of the fact that we have two eyes with overlapping visual fields. Under certain conditions if two slightly different light patterns are presented to the two eyes, either simultaneously or successively, tridimensional single vision occurs. It is customary to describe this process as <u>fusion</u>. What are the necessary conditions for fusion? What is the mechanism of fusion? Why does fusion refuse to take place in conditions where we should ordinarily expect it? No adequate answers to these questions can be made at present.

Under other conditions of binary stimulation fusion may fail to appear, and partial or complete suppression of function in one or the other eye be shown. Under other conditions, such as viewing in a stereoscope black and white squares of equal areas on a gray background, both functions (O.D. and O.S.) may be present to yield the phenomenon of <u>luster</u>, the steely gray which is still not fusion or mixture because its coefficient of reflection does not follow the Tablot-Plateau law.

Again if the two eyes are simultaneously stimulated with differing figures which fulfill certain specifications we may observe the phenomenon of <u>rivalry</u>. There is a more or less regular cyclic alternation and first one eye's figure is seen and then the other. If the two figures selected give good rivalry the replacement of one by the other occurs rapidly and completely. At times the one figure starts to "fade" or wash out from one corner and this fading spreads rapidly until the other antagonistic figure suddenly puts in appearance. At times parts of both figures may be present to form a sort of lattice, later to be replaced by one figure dominating or suppressing the other.

That rivalry exists is an easily demonstrated fact. Its significance, rate, mechanism, etc., are at present not well understood. Of particular interest to us all is the question of its relations to other ocular and optical functions. Washburn* has called attention to rivalry as a neglected factor in stereopsis and has maintained that the presence of rivalry is a necessary condition for fusion. It has been further claimed that rivalry goes on unconsciously in all instances of binocular seeing; that the more or less regular alternation in rivalry practically means that binocular vision is in reality monocular-alternation vision. Certainly we need to know the conditions, rate, properties, etc., of rivalry in normal seeing. But we also need to know what this function is doing in the case of the squinter, the amblyope, etc.

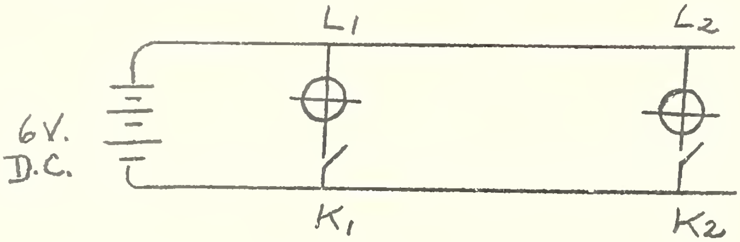
In presenting the materials and suggestions for the observation of some of the phenomena of rivalry it is hoped that many will take pains to observe this function in various types of cases.

That true rivalry presents a number of rather profound problems may be illustrated by the following comparison.

Take two cardboard mailing tubes about 1 inch in diameter and about 18 inches long. Place them in parallel at the proper interocular distance so that there is no overlapping of the fields. Cut two

*Proc. Nat. Acad. Sci., 1933, 19, 773-777.

small round holes the size of a dime in a piece of heavy black cardboard or compressed Masonite and let these holes be about 14 inches apart on the horizontal or 0-180 degree axis. Cover the backs of the holes with architect's cloth or white tissue paper to insure diffusion of the light and arrange two independent light sources for the successive illumination of these apertures. Two small cardboard boxed or baking powder cans containing small 6 volt flashlight lamps or automobile tail light bulbs will do. Wire the lamps so that you can flash them on and off alternately.



Place the screen about a meter distant from the ends of the tubes and line up the tubes so that the flash from L1 may be seen in the left tube only and from L2 in the right tube only.

Now flash the left lamp on for about one second and as its switch is turned off simultaneously flash on the right lamp for about one second and maintain this rate of alternation. Here the left eye sees a bright disk for a second, then this is off and instantly the right eye sees its bright disk for a second and so on. Is this a case of producing rivalry externally?

The answer is no. Rather what one sees is called the pure phi-phenomenon, a well known fact of visual apparent movement. A single light appears to be moving back and forth from R to L and L to R. Movement is seen although there is no moving stimulus. The movement will vary with the intensity of the light, the size of the test patch, the separation distance, the distance of the eye from the target, the time between stimulations, etc. Why does not rivalry produce the same sort of effect? Are the R and L retinas alternately active in the same way in the two instances? If not, wherein does the difference lie?

Following we present 6 stereograms. Cut these out carefully and mount them on stiff cardboard so that each may be viewed in a conventional type of base-out prism stereoscope. Fig. 1 is the one which is widely used for demonstrating the rivalry phenomenon. Place this card in the stereoscope with the right eye figure having its diagonals running from the upper right to the lower left. Adjust the card holder so that it is at an appropriate distance for good fusion for any ordinary stereogram. Have the card evenly illuminated. Look at the figure for 2 minutes during which time record the number and duration of the right eye and left eye phases. In persons with normal vision you may observe that these phases will not necessarily be equal. When a written natural tint filter of 1% transmission is placed before either eye thus creating a high differential of illumination the rivalry rate remains unchanged. Contrary to the findings of Breese*, when corning red No. 244 and green No. 401 filters are placed before the two eyes and Fig. 1 is viewed through them thus creating red and green fields for the diagonal lines, no significant change in rivalry rate is observed.

Whatever the nature of the rivalry phenomenon it is susceptible to practice effect. Last year a 20 year old girl in 18 practice sessions of two 2 minute periods each increased her rate from 17 to 39 complete cycles per minute. Serving as observer myself for the same number of practice sessions I was able to increase my rivalry rate from 13.5 to 27 cycles per minute.

The addition of plus and minus spheres produces a definite change in rate but the direction of this change needs further work in order to establish whether or not

*Psychol. Mon., 1899, 3, No. 11
Psychol. Rev., 1906, 16, 410-415

it is constant in amount and direction. It would be important to determine for any given observer whether there is a difference in the rivalry rate at near point and at far point. R. H. Peckham* has shown that the rivalry rate is not a function of eye movement. The form of the figure and its ground, however, is strongly determinative of the frequency and duration of the phases.

Fig. 2 presents the same general pattern as Fig. 1 except alternate pairs of parallel lines have been blackened in. For the two subjects mentioned above this figure gave the same rivalry rate as Fig. 1 although the contrast coefficient of Fig. 2 is many times that of Fig. 1.

Fig. 3 is a simplification of Fig. 2. We were unable to secure rivalry with the single pair of diagonal lines. Fig. 4 is introduced to illustrate the case where approximately half of the white space in the two test patches is covered by black diagonal lines. This figure does not yield rivalry.

Fig. 5 introduces a complicating factor. The small circles should, upon certain theoretical considerations, produce a depth effect in the surrounds of the diagonals. Study this figure carefully. Note how it differs from Fig. 4. Fig. 4 is introduced as a variant of Fig. 1. Does it yield good rivalry?

Many other types of figures can be drawn for studying the influence of figural shape upon rivalry rate. It is suggested that you exercise your ingenuity in preparing some figures of your own to test any hypothications you may formulate in your examination of the rivalry phenomenon.

Since the rivalry function can be changed by training the question arises as to whether this does not or should not have a place in orthoptic procedures. Just where and how presents a problem for optometrists to decide. Systematic observation of this function in a number of types of eye cases would probably yield interesting and important findings.

*Amer. Journ. Psychol. 1936, Vol. 48, 43-63

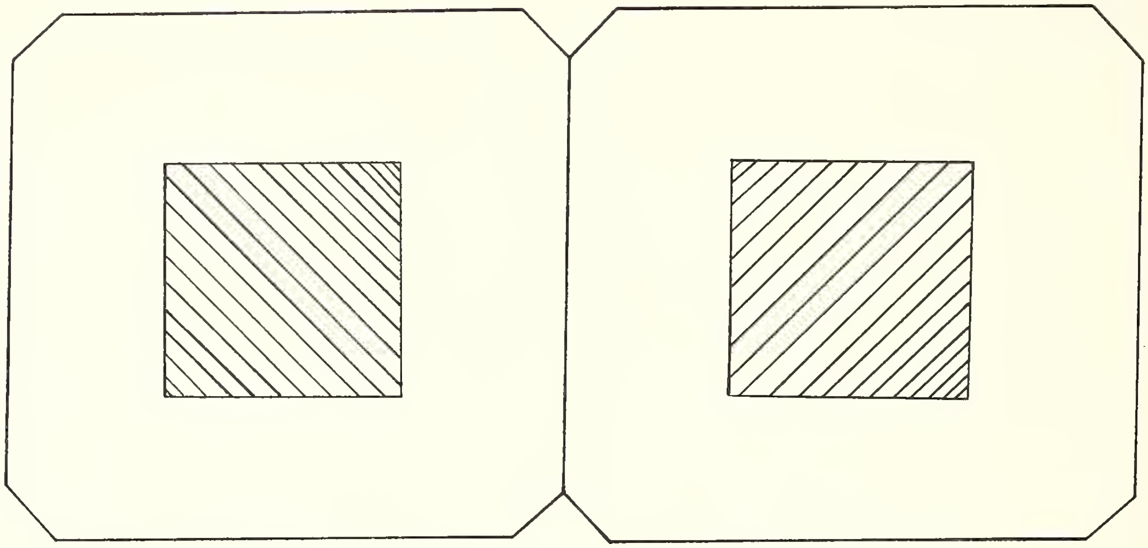


FIGURE 1.

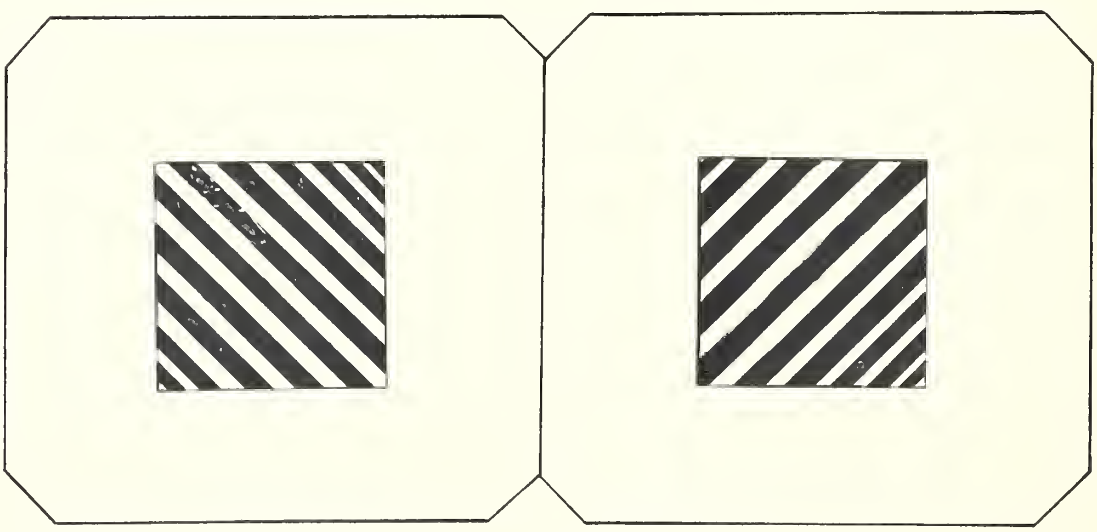


FIGURE 2.

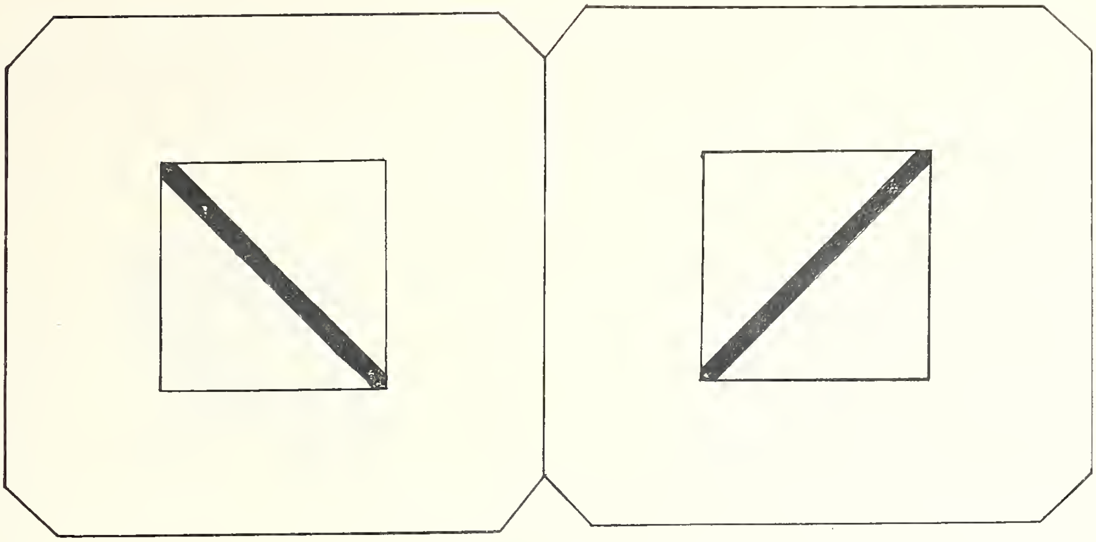


FIGURE 3.

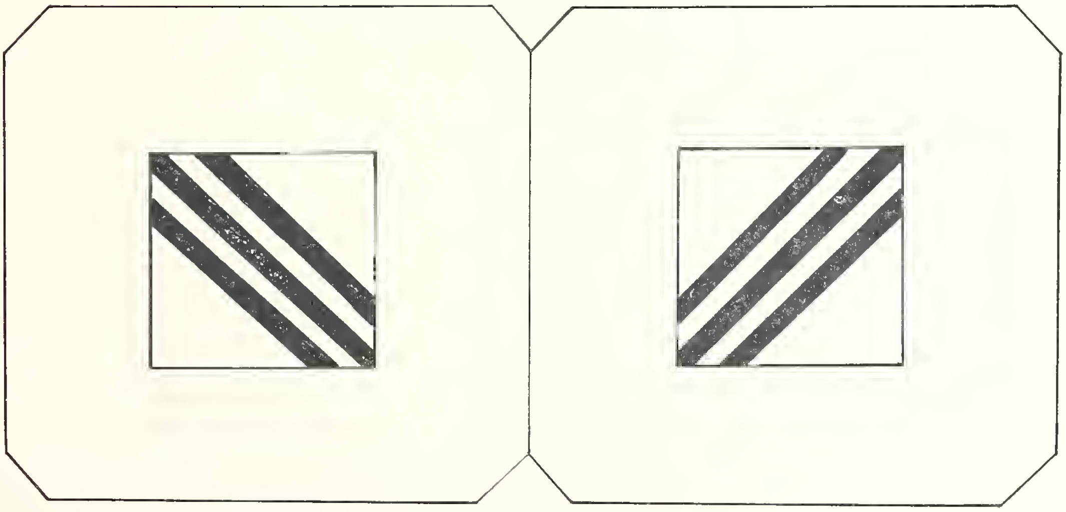


FIGURE 4.

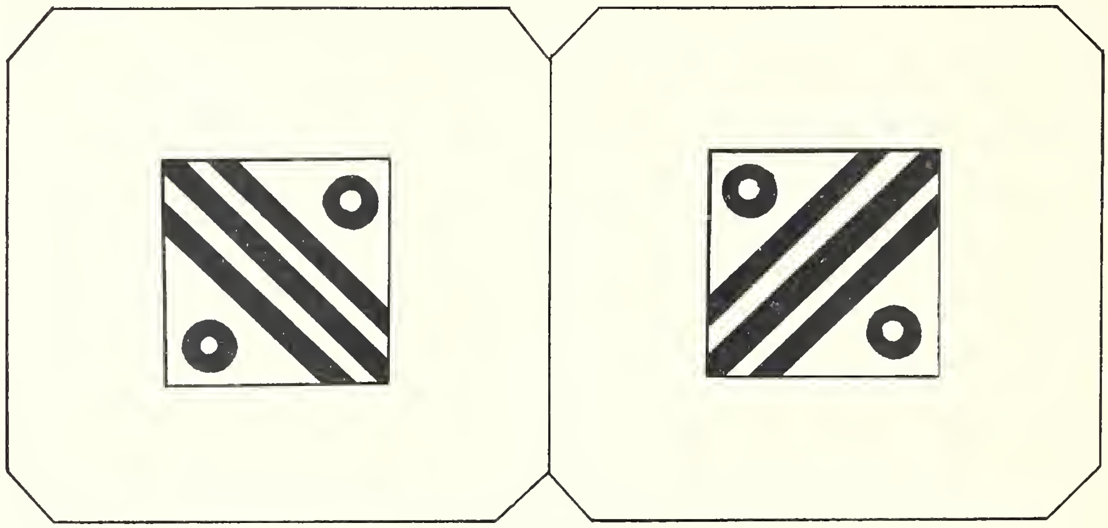


FIGURE 5.

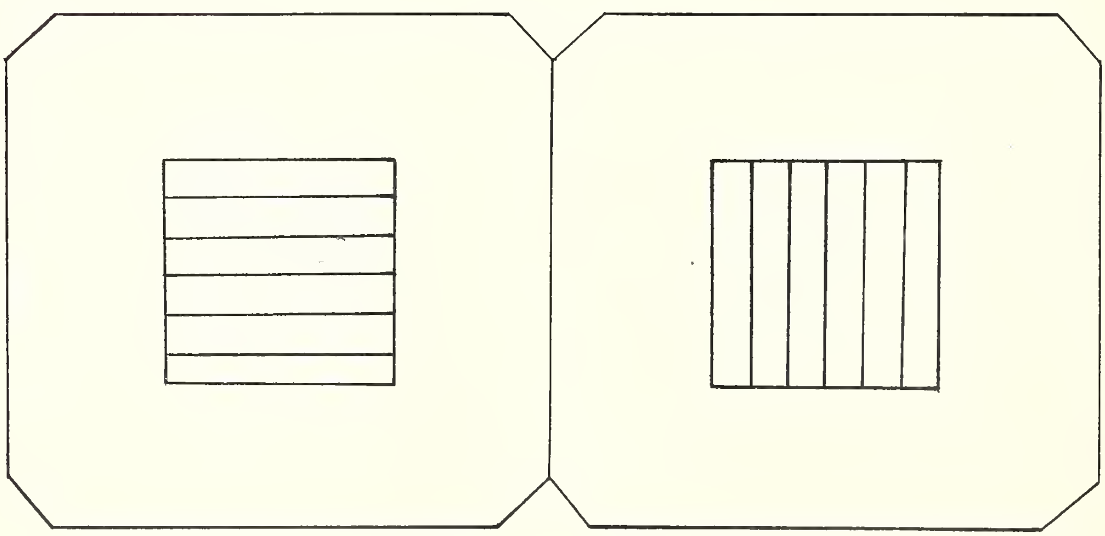


FIGURE 6.

Demonstrations in
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OPTOMETRIC EXTENSION PROGRAM

THE MEASUREMENT OF NYCTOPSIS

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Samuel Renshaw, Ph.D., Ohio State University
with the assistance of Hugh B. McFadden, Ph.D.,
Graduate Clinic Foundation and O.E.P. Fellow in Experimental Psychology,
Ohio State University.

The ability to see effectively in low illumination has received comparatively little attention in proportion to its importance. Nyctopsis, or night vision, varies greatly among individuals who show small or insignificant differences on visual tests made under photopic conditions. Drivers of motor vehicles, airplane pilots, railroad engineers, and C-type cases where there is perhaps a dietary deficiency or some infection are all instances in which the eye examination should include some measurement of the degree to which a person can see discriminatingly in low illumination. There should also be a measurement of the time it takes the eyes to recover from glare in the scotopic state. Suppose for instance that the driver of a car is glare "blind" for 5 seconds while driving at 60 miles per hour. During this time the car moves 440 feet or 146.6 yards! The problem is a very real one particularly in view of the large numbers of persons in occupations demanding effective vision under conditions of low illumination. The frequency of incidence of nyctalopia in the total population is not well known. Satisfactory methods for the quantification of this diminished visual efficiency have not been well developed. It is the purpose of this paper to present a few facts relating to these conditions and to suggest some experiments on the problem which can be carried on in practice.

In general there are 3 types of night blindness. The traumatic type in which fundus lesions are often observed may result from head injuries of various sorts. A second type is due to diseases producing opacities in the media. Peripheral opacities which leave the center free no longer show themselves under high illumination and with small pupils. In this case the opacities do not fall within the pupillary areas. As soon as the illumination is diminished and the pupils dilate they fall within the pupillary areas and interfere with vision. If the opacities are diffused, sight is often better when the pupils are constricted because there is less diffusion of light entering the eye. In the third type there is usually some disturbance of nutrition of the retina often found among those whose diet is not well balanced. Or the condition may be a consequence of diseases of the retina; or it may be idiopathic, due to some chemical alteration of the retina. In the third type since the fovea has a higher light intensity threshold than the periphery, the fovea stops functioning somewhat earlier than the periphery when the illumination level is sufficiently reduced. Instances have been cited where patients report that in very low illumination they see a dark spot in the center of the visual field. In retinitis pigmentosa the reverse condition obtains. The periphery is diseased and under low illumination it ceases to function while macular vision remains intact, but the total field thus becomes too small to serve for the patient's spatial orientation. Hereditary or congenital nyctalopia seems to be due to the inability of the rods to respond to weak light stimulation. Where there is an indication of nyctopsis the usual tests of color vision, perimetry of the disk, and of color and form fields, is indicated. Also indicated is some satisfactory method of determining the degree of nyctopsis.

Since the measurement of this condition involves the control of adaptation let us review briefly some of the facts about this function. According to Troland the absolute thresholds for photopic vision is a light of .0002 meter candle and in scotopic vision it is approximately .00000002 meter candle.

Piper (1903) showed that the minimum perceptible intensity decreases steadily from the beginning of the adaptation, proceeding rapidly at first and then more slowly. After 30 minutes in complete darkness he found that the minimum perceptible intensity was about one ten-thousandth its value at the start. Jones and Flugal (1920-21) showed that 16 minutes dark adaptation was an optimum for nyctopsis measurements. After about 15 minutes in complete darkness the change in sensitivity is slight.*

The adaptation of the fovea presents an entirely different picture. The first accurate work was done by Hecht (1921-22) who showed that dark adaptation of the fovea is very rapid, being practically complete after a few minutes. Hecht's measurements were made with extreme red light, in order not to excite the peripheral rods. He found that after 4 minutes there is no significant foveal change. Kohlrausch (1922-31) and Deiter (1929) have confirmed Hecht's findings.

Another important consideration in making these measurements is the relation between intensity discrimination and the size of the visual field. Lasareff showed that the Weber constant $\frac{\Delta I}{I}$ diminishes from a value of about 0.42 at 5 minutes of visual angle to about 0.1 at 18 minutes of visual angle and remains virtually constant at 0.05 from 40 minutes to 80 minutes of visual angle. Thus a test patch which subtends 20 minutes of visual angle at the eye is sufficient for work of the type to be described later in this paper.

The method of producing satisfactory dark adaptation is simply to set the patient in a completely darkened room and keep him in this condition until the required time has elapsed. The claim that occasional short flashes of light hastens the process of dark adaptation has been found experimentally not to be justified.

During the first world war Jones, at the University College, London, tested a number of British aviators in the psychological laboratory for nyctopsis. He used 12 men in his main experiments all of whom had had extensive flying experience and had passed all of the medical and ophthalmic tests satisfactorily. The author reports, for example, that subject E after 4 minutes of dark adaptation showed a minimum light threshold of 0.00127 meter candle. Subject C after the same period of adaptation had a threshold of 0.00009 mete candle. The relative sensitivities are proportional to the reciprocals of the intensities of the stimulus required to excite the receptors. Consequently Jones asserted that C was 14 times as sensitive as E so far as the minimum visible threshold for light was concerned.

After 40 minutes of adaptation B's eyes responded to an illumination of 0.000153 meter candle and L's to a light of 0.0000 meter candle. It was then concluded that L was 25 times as sensitive as B. In the four cases cited above no striking differences were found in the results of daylight visual tests. At present I doubt whether we have any exact information as to the limits of toleration for restricte vision in low illumination which will safe ly permit a man to fly an airplane, drive a motor car, or operate a locomotive at specified levels of very low illumination. That there are limits for safety in these functions goes without saying. Part of our national defense program should and probably will call for the more precise investigation of this function of vision. It is hoped that the following suggestions may start a considerable number of optometrists to the making of a first hand examination in the comparison of the visual efficiency of persons who have normal nigh vision with those who are known to be limited in their ability to see in low illumination.

It is significant that previous experimentation has shown that visual acuity taken in daylight does not correlate significantly with light sensitivity at any adaptation time. It is further true that light sensitivity does not correlate significantly with visual acuity in dim light and that visual acuity in dim light

*Since the Purkinje Effect is usually absent or disturbed in these cases, it is a question whether green light should be used in determining the minimum peripheral sensitivity. Perhaps the safe procedure is to use green for the periphery and red for the fovea. Some rods are sometimes found in the fovea. (Duke-Elder).

correlates rather highly with that in much dimmer light. The testing for light sensitivity can be confined to a region of about 10 degrees around the fovea since it was found that results secured for 20 degrees, 40 degrees, or 60 degrees toward the periphery gave approximately the same results. Since an individual's acuity in daylight is no criterion of his light sensitivity the mere fact that a person passes successfully any number of visual tests under photopic conditions is no guarantee that he may not be suffering a considerable impairment of his night vision.

The primary consideration to be determined in any case where there is a suspicion of nyctopsis is the measurement of light sensitivity under 2 conditions. First, at the start or early in the process of dark adaptation. This determination should be made, say, at about 4 minutes after the start of dark adaptation. Second, the determination of the change in sensitivity that takes place during the remainder of the period of adaptation. Thus if we determine sensitivity after 4 minutes of adaptation and again after 16 minutes of adaptation the difference between these 2 measures will give us an indication of the amount of increased sensitivity produced by the 12 minute period of dark adaptation. In the night blind individual this increase should be relatively small as compared with a person whose night vision is normal. We recommend the following simple procedure for making these determinations.

Secure a couple of one-half watt General Electric Neon glow lamps. These can be obtained from any good electric supply dealer for about 35¢ apiece. The lamp globes are fitted with a standard screw base and the bulbs are about the size of an English walnut. The filaments are two half-cylinders of metal and they emit a soft orange-red light when placed in 110 volt alternating current circuit. If direct current is used only one half of the filament will emit light. These little lamps will be found very interesting and useful. If the eye is held stationary and the lamp is moved about in the visual field it will be seen to flicker. When held stationary and seen foveally the illumination will appear constant. This effect is simply due to the difference in the flicker limen between foveal and peripheral retina. If one of these lamps is placed in a key type socket attached to an extension cord about 8 ft. long and a suitable shade or reflector attached to the socket, it then can be used for illuminating the test patches without light entering the observer's eyes. At a distance of 1 ft. from a Westinghouse foot candle meter of the grease spot photometer type, one of these glow lamps gave a reading of .03 lumens or foot candles of illumination per square foot. At 2 ft. distant the reading was .016 lumens.

In order to test the minimum illumination which would give a visual discrimination of form, we arranged a table in a dark room on which a meter stick was laid flat. At the one end of the meter stick a square of gray paper, 8" x 8", was set in a vertical position for background. This paper was number 9 of the Hering series of grays and has a coefficient of reflection of 0.24. Pasted on the face of this square were a number of shapes similar to those shown in Fig. 1 cut from gray number 6 of the Hering series which has a coefficient of reflection of 0.33. The subject is dark adapted for about 15 minutes and his eyes placed at the proximal end of the meter stick. The experimenter stands at the side of the table using the palm of his hand for the reflector of the small Neon glow lamp. The lamp is turned on and made to illuminate the test patch from a position of 30 inches on the meter stick. The lamp is slowly moved forward and the observer is instructed to report the first instant at which he can discriminate any brightness differences apparent in the test patch. The position of the lamp is read directly from the meter stick and recorded. The lamp is extinguished while this recording is being done. The illumination is then resumed from this position and again moved slowly toward the test patch with the observer instructed to report the first indication of his ability to perceive forms in the test field which differ from the background. This position is noted. It is not necessary to demand the ability to name or recognize the shapes at this position. From this position the light is moved slowly forward until the observer is able to accurately identify the shapes and positions of the slightly

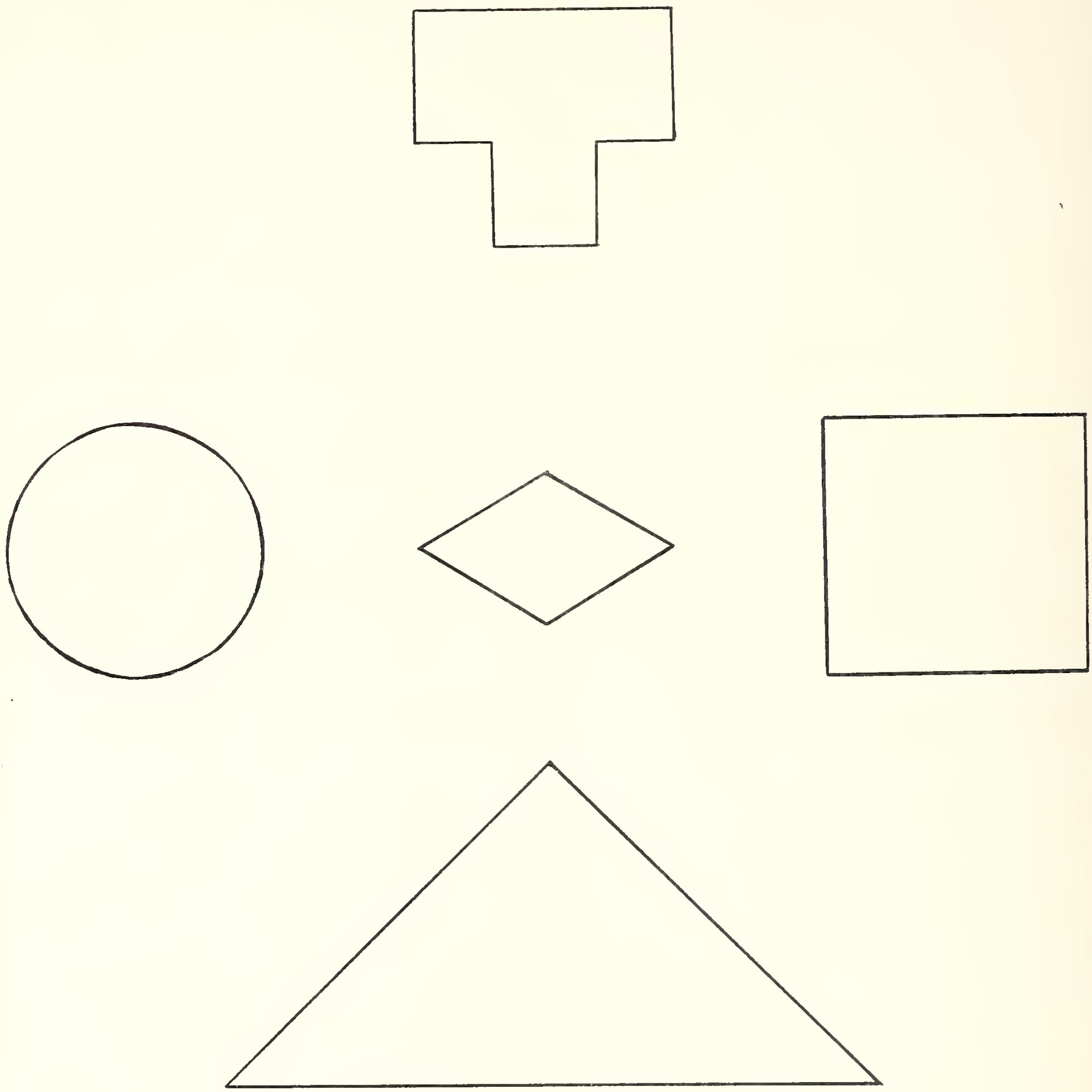

FIGURE I.

The shapes are of the lighter gray and can be fixed to the darker gray background with rubber cement. Note that the shapes are symmetrical enough so that the card may be used in four orientations - the large triangle to the right, left or above or below.

brighter test objects made up of lighter grays on a slightly darker gray background. This position is noted and recorded.

Two students, age about 20, who give every indication of having normal vision in low illumination both reported the first ability to discriminate the general brightnes of the undifferentiated test field when the glow lamp was 18 inches from the fiel At 16 inches both were able to report spots of differential brightness in the

field but were unable to discriminate the forms. At 14 inches both could report the forms perfectly. With suitable instruments the precise photometric description of the illumination of the test patch and the illumination reaching the eyes of the observer may be described. This apparatus is admittedly crude and imperfect but it is satisfactory to demonstrate the fact that individuals may be found who differ greatly in the intensities of illumination required for form discrimination under low illumination where the brightness difference between the test figures and the background as in the above instances measures about 9 percent difference in the coefficients of reflection.

If there is available a calibrated neutral tint optical wedge, then an apparatus could be set up in which the illumination from the glow lamp could be restricted to a small circular test patch about a centimeter in diameter. Working from the opaque end of the wedge by a limiting method the point at which the light patch could just be discriminated would comprise a measure of threshold sensitivity. Such a measure taken after 4 minutes of dark adaptation and after 16 minutes of dark adaptation would provide the basis for determining the status of the individual's eyes to show the normally expected increase in sensitivity which accompanies dark adaptation.

A second test should consist of a determination of Snellen acuity under ordinary daylight conditions. That is, under the usual conditions of determining acuity with a Clason or some similar form of apparatus as the measure is conventionally taken in offices. With the aid of a cardboard Snellen chart acuity is then taken after 16 minutes of dark adaptation under low illumination. It is suggested that the term low illumination in the previous sentence should be approximately 0.02 lumens. That is approximately the illumination received by the card when a Neon glow lamp is placed about 14 inches in front of the chart.

A third significant test has to do with the ability of the dark adapted eye to recover from glare. A suggested procedure here is dark adapt the observer for a minimum of 16 minutes. Arrange a white card 20" x 30" about 6 ft. from the subject and slightly eccentric to the line of sight. Place the test patch shown in Fig. 2 at eye level 6 meters distant from the subject

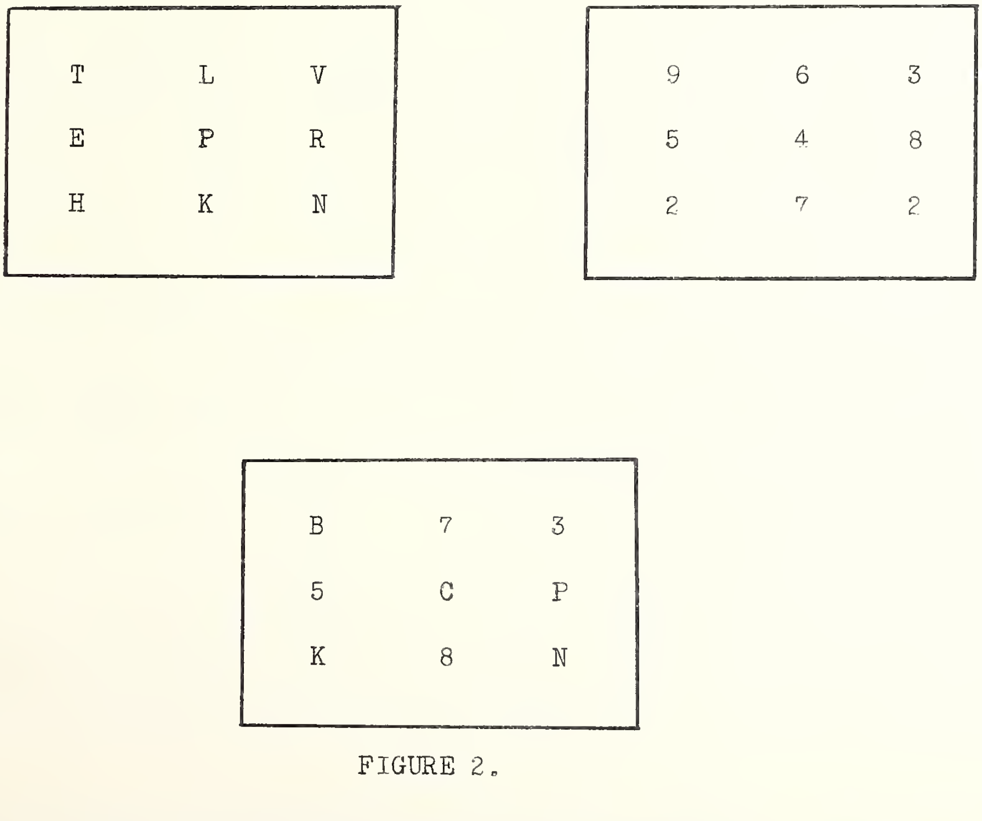

FIGURE 2.

These test cards are prepared from the same two grays as indicated for Fig. 1. The letters and digits should be cut from the lighter gray. If the ground size is 8" x 8" the letters and digits should be about 3 cm.

in height and width. This corresponds to the standard Snellen 70 ft. or 21.75 m. line. The glare recovery test should be tried with such a test object at 6 m. and based on experience, changes can be made in the size-distance relations according to the subject's response.

and cover the front with a second piece of gray cardboard informing the subject that after the glaring stimulation he is to fixate the test patch, and as soon as he is able, to call out the letters or numbers seen on this card. Light from a thousand watt lamp or number 2 photoflood in a suitable reflector is then thrown upon the large white cardboard for 3 seconds, the subject instructed to gaze at the white cardboard during this time of stimulation. As soon as the glaring light is extinguished the experimenter should uncover the test field and start timing with a stop watch the duration of the period of recovery, that is, until the subject's dark adapted eyes are able to read the letter pattern of gray on gray.

Standard test objects, illumination and test procedures should be set up and used uniformly and norms of ranges of toleration established as occupational criteria for the hemeralopia-nyctalopia functions.

The tests of threshold sensitivity, foveal and peripheral; of photopic and scotopic acuity; and of recovery-time from glare should give a fair picture of the status of night vision, particularly if taken in conjunction with some other observations previously indicated.

REFERENCES

1. Duke-Elder, W. Stewart, Textbook of Ophthalmology, I, Mosby, St. Louis, 1937, 897, 970-973.

2. Fuchs, Textbook of Ophthalmology, (Duane tr.) 1919, p.635

3. Wentworth, Hazel A., A Quantitative Study of Achromatic and Chromatic Sensitivity from Center to Periphery of the Visual Field, Psy. Mon. 1930, 40, No. 3 whole No. 183, pp. 189.

4. Jones, Ll. Wynn, A Method of Measuring Nyctopsis, Br. Jour. Psychol., 1920-21, 11, 299-319.

5. Hecht, Selig, In Murchison, Handbook of General Exper. Psychol. Clark Univ. Press, 1934, pp. 704-820.

6. Houstoun, R. A. Vision and Color Vision. Longmans, New York, 1932, pp. 1-99.

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OPTOMETRIC EXTENSION PROGRAM

VISUAL CONTRAST

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Samuel Renshaw, Ph.D., Ohio State University
with the assistance of Hugh B. McFadden, Ph.D.,
Graduate Clinic Foundation and O.E.P. Fellow in Experimental Psychology
Ohio State University

Almost everyone is familiar with contrast effects. They may be observed in brightnesses, hues, sizes, shapes, motions, etc. If an artist is painting a picture and the greenest green paint he has is not green enough, he does not worry. He simply places a little bright red somewhere near, and in its presence his green now is green enough. Brightnesses may be made more or less bright; test objects may be rendered more or less visible, simply by arranging the proper relations for contrast.

Almost all theories of contrast go back originally to Hering. They hold essentially to the view that contrast effects are physical and physiological, and reduce to simultaneous light induction. A bright patch induces black in its whole surroundings, the magnitude of the effect decreasing in an unknown way with distance. Since <u>black</u> itself is said to be a contrast-effect and hence no local stimulation process produces it, a dark patch does not induce brightness in its surrounds, as the converse to the first case, except perhaps under certain very special conditions. Aside from the difficulty of explaining how this latter phase of the process works, the Hering principle is based on the theory that contrast is summative and absolute. The effect varies with areas, intensities, separations, etc. Accordingly, also, it is presumed that the number of retinal elements firing, particularly rods in the case of brightness contrast, is the principal determinant of the magnitude of the contrast effect.

The conventional method of designating and measuring contrast, employed by engineers, physicists, physiologists, etc., may be illustrated as follows: A test object on its background is said to have "65% contrast." This means that if the brightness of the test object (b) is subtracted from the brightness of the ground (B), and this difference divided by the brightness of the ground (B), the quotient will be the degree of contrast (C), if proper steps are taken to convert it into percent.

$$C = \frac{(b-B)}{B}$$

This formula can be written:

$$C = \frac{(B-b)}{B}$$

where the ground has a greater brightness than the test patch. The difference in brightness which is the numerator of the fraction is always a positive number. Contrast thus depends simply upon the one thing - the ratio of the brightnesses of figure and its ground, if the Hering theory or one of its derivatives is correct.

But the late Professor Troland used a little different way of denoting contrast. For him, $C - k\ (b-B)$ where <u>C</u> is again the contrast effect, <u>b</u> and <u>B</u> are the figure and ground brightnesses and <u>k</u> is a constant, which under certain most favorable conditions may equal 1. <u>k</u> is a parameter of all such conditions as area, shape, distance of the contrasting surfaces, etc., which Troland knew could and did affect the amount of the contrast. Thus it seems that a first step was taken away from the over-simplicity of the Hering concept. More recently we have had to move still farther away from this position, because we must expand our view of contrast to cover demonstrable instances not cared for in previous theories, and we must

recognize that the full theoretical significance of contrast problems were not realized in Hering's day. Nor are they realized today by those whose training and point of view has been confined to narrow lines.

It is our object to supply you some contrast demonstrations which may interest you and set you to work upon the problem. Let us begin with a simple case of brightness contrast. Secure a supply of black, white and medium gray papers. Cut 8" squares of black, gray and white. In the center of each place a 1" square of the same gray. Place the three large squares in a horizontal row on a table in a good light. You will note that the small gray patch on the black looks distinctly brighter, and on the white distinctly darker. Now cover them all with a sheet of white tissue paper and note the change. If you own or have access to a suitable photometer, measure the reflectances of the papers and compute the per cent contrast using the formula given above.

Now, take a Maxwell disk rotator and place on it white and black disks. Adjust the proportions of black and white until you secure the closest possible match of the small gray squares, viewed both with and without the white tissue. Now match a sample of the gray independent of any ground. From these data you can easily compute the increased or decreased brightness induced by contrast. How do the matching results agree with the Hering method of denoting the contrast? How do you account for the difference?

Now examine carefully the middle square--the gray on gray. Look at it with and without the tissue cover. Look at it at 16 inches, at 3 feet, 9 feet, 20 feet. Describe carefully what you see and try to render a theoretical "explanation" of the contrast effect--where, of course, $(b-B) = 0$ in the Hering formulation.

Contrast effects can be tremendous as everyone knows who has looked into the eyepiece of a Macbeth illuminometer. Here you see a doughnut shaped ring of light, which can be varied in brightness to match the inner spot or test patch to be measured. If this spot is a mid-gray it can be made to appear as white or as black, although remaining perfectly constant in brightness, merely by changing the brightness of the external ring of light.

Opposing any hue or brightness inductance is always the phenomenal fact of hue and brightness constancy. Often the unexpected contrast effect either fails to materialize or it occurs in the wrong direction, due to the operation of this factor of constancy, which is a tendency for things to maintain their "real" hues or brightnesses even under relatively extreme conditions favoring large contrast distortions.

Appurtenance is a further factor in contrast. Its meaning can be demonstrated and made clear by repeating an experiment made some years ago by W. Benary.

From a piece of black paper or black cardboard prepare a cross like A in Fig. 1, and mount this on a white cardboard background about 11" x 14", or 16" x 20". The width of the arms of the cross should be about 3 cm. and the length of the protruding arms of the cross about 4 cm. Prepare two small triangles cut from a neutral gray paper such that the base of the triangle is about 2 cm. These triangles can be practically equilateral so that they may be placed as indicated in A of Fig. 1. That is, small gray triangles of equal brightness are placed at g_1 on the upper vertical bar of the cross and g_2 on the background at the angular junction of the right and lower arms of the cross. The optimal observation distance is from 4 to 8 meters. Note that the upper triangle g_1, is a part of the figure and lies on or within the cross; while g_2, the lower triangle lies on the white ground. Note also that g_2 actually has a little more black and a little less white in its surrounds than g_1. According to a summation theory of contrasts, g_2 should therefore appear brighter than g_1. But you will note that g_1 is clearly brighter than g_2. The amount of the difference in brightness can be measured by a matching method. This consists of placing black and white disks on the Maxwell disk rotator and adjusting the proportions of white and black until a matching gray is secured for g_1, and g_2. The difference in brightness can therefore be specified in terms

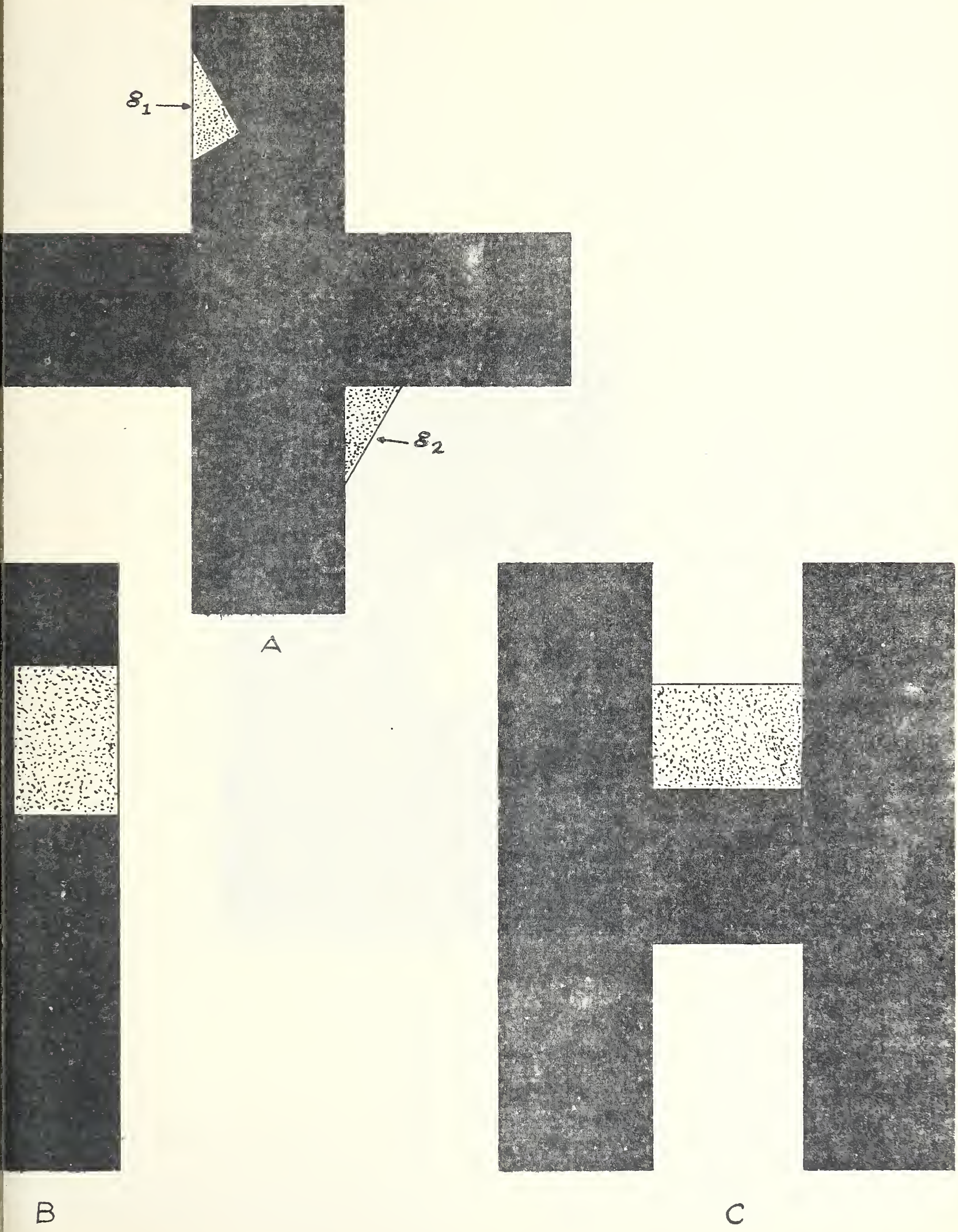

FIG. I. BENARY'S FIGURES

of the difference in the coefficients of reflectance of the two test patches. In the above instance the contrast effect depends on whether the small gray triangle is seen as belonging to or as a part of the figure or of the ground. If it is seen as part of ground, it tends to take on the properties of the ground, and similarly for figure. This is the principle of appurtenance. Because of its influence brightness differences may be observed which are the exact reverse of the effect demanded by a summation theory of contrast. If we suspect that the effect is due to some peculiarity of the shape of the figure we have used this can be proven by repeating the observation on parts B and C, of Fig. 1. In this case rectangular patches of gray are inserted as shown in the figure, on the bar of the I and above the bar of the H, and the same result will be noted.

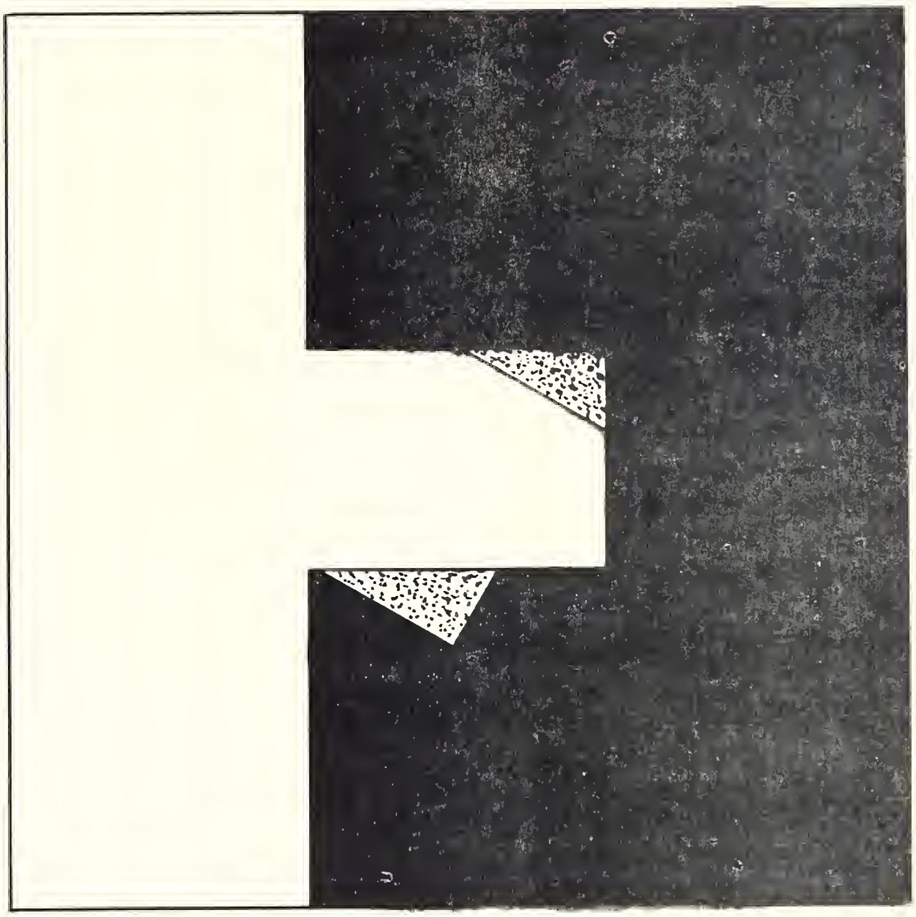

FIG. 2

FIGURE AND GROUND

AND SURFACE APPURTENANCE

In figure 2 again, two small gray triangles are placed in such positions that one may see the figure normally as a gray-on-black as ground and therefore as brighter than the gray-on-white. This is under the condition where, upon first looking at the whole pattern, the black portion to the left seems to be a figure

set in a white ground. By studying the figure carefully it is possible to see the left and right portions as simultaneous equivalent figures. Where this is done it does not alter the brightness relation between the two grays, that is, the gray-in-black is still brighter than the gray-in-white, and so we must conclude that the brightness difference depends not upon figure and ground but upon surface appurtenance. Experiments such as the foregoing demonstrate that brightness contrast is a function not only of brightness differences but of other more complex relations of figure and ground. One must conclude that all theories which base the contrast effect wholly upon a function of differential brightness are therefore incomplete and unacceptable.

Suppose now we consider the case of color contrast because virtually all contrast effects involve a combination of brightness, color, form, etc. Where color is involved the contrast effect is always in the direction of the greatest qualitative opposition. The contrast effect will be greater the more saturated the inducing color. Nearness of the contrasting surfaces will be found to increase the contrast effect just as the elimination of contours will produce the same result, and finally color contrast will be at its maximum when brightness contrast is eliminated. The converse would logically follow, that in order to reduce color contrast effects we should make brightness contrast a maximum.

A critical test of conventional theories of contrast is found in some simple instances of color contrast. One of the most famous of these is the experiment made by Max Wertheimer in 1916.

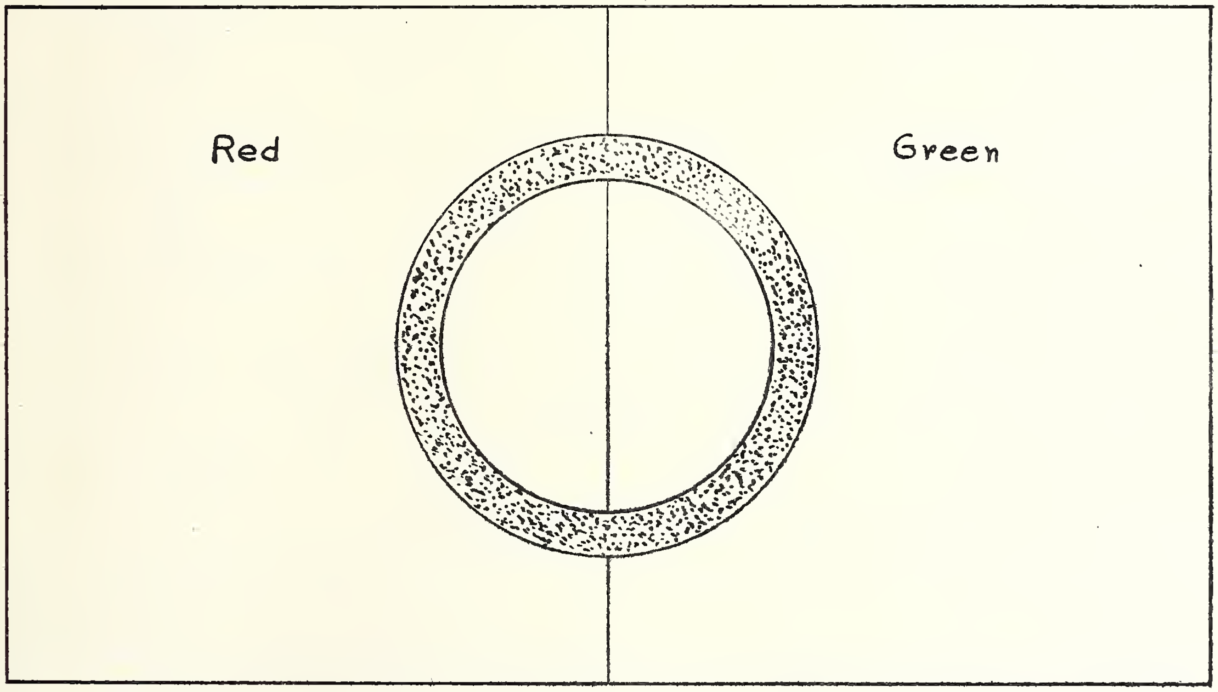

FIG. 3

WERTHEIMER'S EXPERIMENT

A ring of medium gray is placed on the overlapping backgrounds of red and green, as shown in Fig. 3 above. So long as the gray ring rests upon the two grounds and is seen as a unitary structure, color contrast will remain absent or at negligible minimum. If a ruler or a heavy string is now laid upon the line separating the red and green grounds, and if in phenomenal vision this bisects the gray ring so that it is seen as two semi-circles on two different grounds, a striking

color inductance will instantly appear. Remove the string or the ruler and the induced colors disappear. How shall we account for the failure of color contrast under conditions which according to conventional theories seem ideally suited for it? One possible answer is that so long as the gray ring remains a unitary structure its internal forces of organization will resist any tendency to destroy its color, brightness, or form. Bi-section destroys this unity and there is an immediate contrast inductance.

An equally striking demonstration of a col or contrast effect which is in opposition to conventional theories is an experiment described by Mrs. Heider.

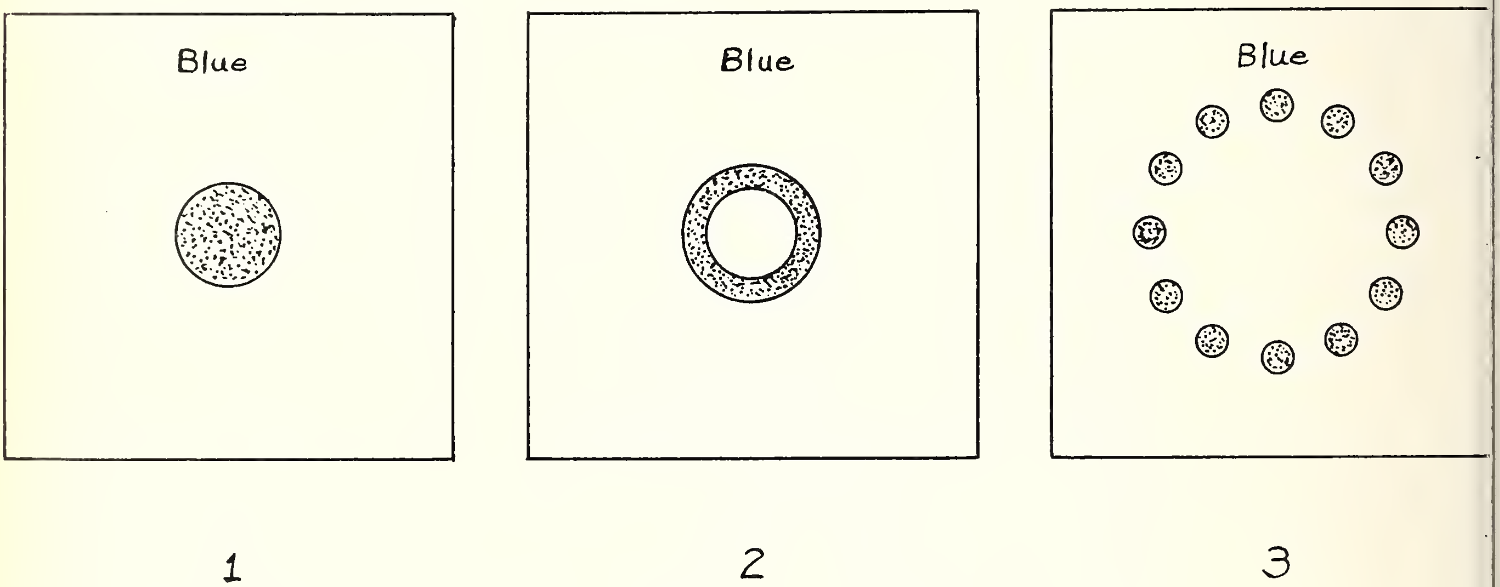

FIG. 4

MRS. HEIDER'S EXPERIMENT

The backgrounds marked 1, 2, and 3, in this figure are square patches of bright blue. In No. 1, the central figure is a gray annulus. In No. 2, the gray ring is made equal in total area to the annulus in No. 1. In No. 3, a series of small disks of the same gray are arranged as a circle. In all three cases the total area of gray is the same. The theory demands that the contrast effect should be greatest in No. 3, next in No. 2, and least in No. 1. Observers uniformly have reported that the opposite holds. The maximal contrast effect is found in No. 1, the figure having the simplest and most perfect organization, and the least contrast is seen in No. 3. Conventional theory again demands that No. 3 should be more colored, but observation reports it to be least colored. Apparently the more coherent the figure the greater is the inductance.

This conclusion seems to be a direct contradiction of the result observed in the experiment shown in Fig. 1 above. There, the most cohesive figure was least colored, while in the Heider experiment it is the most colored. Professor Koffka offers the following explanation for this fact: In the experiment of Fig. 1, "the uniformity which was enforced by the greater cohesiveness had to be a neutral uniformity, while in Mrs. Heider's experiment no such connection between uniformity and neutrality exists." Any interpretation of the difference between the two effects should be based on the consideration of differences in structural organization, in figure-ground relations in the manner in which the observer sees the total figure, etc. The complete

statement of the laws of brightness and color contrast can therefore not be formulated until complete descriptions have been rendered of the mechanics of visual pattern discrimination.

REFERENCES

1. Luckiesh, M. and Moss, F. K. The Science of Seeing, Van Nostrand, N. Y. 1937, pp. 124-137.

2. Fry, G. A. and Bartley, S. H. Effect of One Border in the Visual Field Upon the Threshold of Another. Amer. J. Physiol., 1935, 112, 414ff.

3. Cobb, P.W. The Effect on Foveal Vision of Bright Surroundings. J. Exper. Psychol. 1916, 1, 540 ff.

4. Cobb, P. W. and Moss, F. K. The Effect of Dark Surroundings Upon Vision. J. Franklin Inst. 1928, 206, 827.

5. Troland, L. T. Psychophysiology, 3 Vol. Van Nostrand, N. Y. 1923.

6. Koffka, K. Principles of Gestalt Psychology, Harcourt, Brace. N. Y. 1935.

7. Titchener, E. B. Experimental Psychology, Students and Instructors Manuals, 4 Vol. McMillan, N. Y. 1915.

8. Geldard, F. A. Brightness Contrast and Heyman's Law. J. General Psychology, 1931, 5, 191-206.

9. Hess, C. and Pretori, H. Simultaneous Luminosity Contrast. Arch. f. Ophth. 1894, 40, 4, p 1. ff.

10. Houstoun, R. A. Vision and Color Vision, Longmans, N. Y., 1932, 168-180.

11. MacLeod, R. B. An Experimental Investigation of Brightness Constancy. Archives of Psychol. 1932 No. 135, pp. 101.

12. Ferree, C. E. and Rand, G. Contrast induced by color so far removed into the peripheral field as to be below the threshold of sensation. J. General Psychol., 1932, I, 466-472; 1933, 9, 450-452; 1934, 11, 193-197.

13. Fry, G. A., New Observations related to the problem of Color Contrast. J. Exper. Psychol., 1934, 17, 798-804.

14. Benary, W. Observations from an Experiment on Brightness Contrast. Psychol. Forsch., 1924, 5, 131-142.

Demonstrations in
Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

COLOR PHENOMENA

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Samuel Renshaw, Ph.D., Ohio State University
with the assistance of Hugh B. McFadden, Ph.D.,
Graduate Clinic Foundation and O.E.P. Fellow in Experimental Psychology,
Ohio State University

Before attempting demonstration of various phenomena of color discrimination it will be necessary to clarify certain principles and certain terms used in the description of these effects.

Color vision is essentially a function of photopic vision. There is an old saying that in the night all cats are gray. Duplicity theories assume that color discriminations are associated with functions of the cones and that brightness is a rod function. It has been shown that cones only behave as cones in the presence of rods. In the fovea, for example, where the cones are maximal and only a few rods are found, the change in color and brightness relations known as the Purkinje phenomenon does not follow the same principle as it does further out in the periphery. The reason for this is said to be that the rods produce a hormone or sensitizing substance necessary for cone functioning in color vision.

The adequate stimulus for color discrimination is a narrow band of radiant electromagnetic energy within the limits of wave lengths about 400 mu mu to 700 mu mu. The symbol mu mu or millimicrons represents millionths of a millimeter. The eye, therefore, is sensitive to only a tiny portion of the whole radiant energy spectrum which varies from the extremely short cosmic rays to radio waves many thousands of meters long. Ordinarily red light means a dominant wave length somewhere between 647 and 760 mu mu in length, orange is 588 to 647; yellow, 550 to 588; green, 492 to 550; blue, 433 to 492 and violet, 300 to to 433. Newton was the first to show that when a beam of sunlight passes through a prism, colorless light from the sun is resolved into a solar spectrum. If now these various colored spectral lights are collected by a curved mirror and focused upon a point, then the mixture of all the spectral hues produces the same colorless white light which entered the prism originally.

It should be remarked at this point that the history of work on color is a long and involved one. The reasons for this are obvious. Variations of interest among scientists, artists, technicians and others has led to many different systems of measuring and describing colors. Only in comparatively recent years has a concerted effort been made to introduce some uniformity in the terminology and standards for color description. More than 100 years ago it was shown by Clerk Maxwell that if colored disks are placed on rapidly spinning tops or rotated by fast spinning motors, the same visual mixture could be produced as would follow the mixing of colored lights. If we arrange a suitable apparatus so that we can produce monochromatic bands of light and if we begin at the red end of the spectrum and mix every light with every other wave length within the visible limits, we shall observe that some of these mixtures produce hues which are obviously a sumation of the two components. Others produce only achromatic colors - white, gray or black. When two hues mix to produce a "colorless" gray, we classify such hues as complementaries. When they mix to produce a new hue (whose characteristics will depend on the relative proportions of the two or more components in the mixture) we classify them as noncomplemen-

taries. When this process of mixing every color with every other color in the visible spectrum has been completed and we analyze the result and generalize from it, it has been shown that the entire spectrum can be made by the mixture of three wave lengths. These have been called cardinal stimuli by the International Commission of Illumination and in this system they represent lights of wave lengths 700 mu mu, 546.1 mu mu, 435.8 mu mu. Since all the colors of the spectrum are capable of being produced by a mixture in the proper proportion of the red, green and blue lights, these have been designated as the primary colors of the physicist. Bear in mind that we are only saying that the mixture of these three wave lengths will produce lights which are seen by the eye as a direct visible spectrum. From the standpoint of physiology and psychology, we must take into consideration the additional fact of the stimulation of the retinal elements by lights of different wave lengths. If we follow the color system of Hering, for example, and we wish to show how we can match the hues in the visible spectrum, we must use combinations of three pairs of stimuli, two chromatics and one achromatic, which behave like antagonists or complementaries. These three pairs of light stimuli are red and green, blue and yellow and black and white. At least one system of color description maintains that there are 7 primaries, namely: red, green, blue, yellow, black, gray and white. From the point of view of the artist, red, blue and yellow are his primaries because green paint on his palette is made by mixing yellow and blue. But if we mix yellow and blue with the Maxwell disk rotation method, we produce not green but gray. It thus becomes clear that primary colors are defined in terms of practical interests. Any color can be (and probably is) a primary color because there are numerous combinations of three or more wave lengths, the mixtures of which in the proper proportion, will produce the visible spectrum. For physics the primary colors are one thing, for the artist, another, for the physiologists another and for the psychologists still another. We shall show a little later for example, that color experience depends upon other things than the purely physical characteristics of the light waves. In order to assist in thinking and talking about colors as we experience them, it becomes quite helpful to use a diadatic kind of diagram referred to as the color pyramid or color solid. This is illustrated in Figure 1 following.

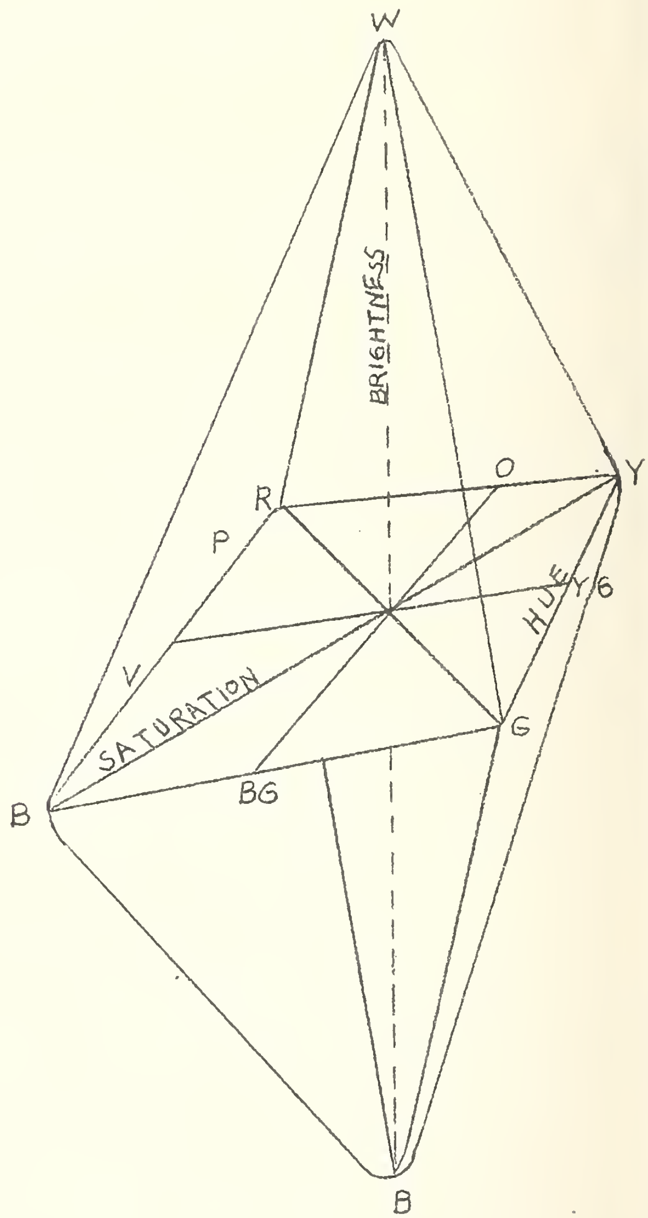

FIGURE I.

Color Solid

You will note that we start with the red and move to yellow, green, blue and violet as we pass around the plane which divides the solid into two almost symmetrical halves. It is sometimes customary to represent this plane as rectangular because the yellow and green are tilted slightly toward the white, while the red and the blue, the darker colors, incline slightly toward the black. Red and green are in the opposite corners of the square base because they are complementary to each other, i.e., when mixed in the proper proportion they produce gray. Likewise, yellow and blue are placed diagonally opposite because they too are complementary and produce gray. The eye can make about 120 hue discriminations as it passes from the extreme angular position of primary red around the solid and back to the starting point. The colors reading around the circumference of this figure are called hues. Hue is the special attribute of color experience in which one color differs qualitatively from another. The hue names are reds, oranges, yellows, yellow greens, purples, etc. The colors at the points of the base plane are said to be maximally saturated when they are maximally pure and intense. Thus saturation means that a red contains nothing but red, blue nothing but blue, etc. The positions of the maximally saturated colors are, therefore, represented on the color solid by points which lay not only farthest removed from their complementaries and noncomplementary hues, but also farthest from the achromatic colors, namely the white, gray, black series. Thus, saturation is represented by the distance away from the perpendicular midline through the solid, while hue represents a particular direction from this reference point. The third attribute in describing any color is brightness. This represents the distance above the central plane toward white or below this plane toward black. It is customary in some systems of color description to think of any visible color as an imaginary point situated somewhere within this color solid.

A difficult problem is presented by the fact that by definition hue, saturation and brightness are independent attributes of colors. But this independency does not extend very far because in order to desaturate a color all that we need to do is either mix with it some of its complementary hue or increase or decrease its brightness. If we add gradually more and more white light to red for example, the red will pass through the pinks until it reaches the position W or white on the achromatic line. In other words, we may have a strong red color but if we mix enough white light with it we may almost completely desaturate it to a point where the eye no longer sees any red in it. Thus, saturation depends upon brightness and under certain circumstances upon hue. The conventional method of designating any color is to specify its hue, its saturation and its brightness.

Psychologically, it is necessary to recognize the fact also that proper specification of any color must involve a recognition of its dependence upon such factors as contrast, area, adaptation, and what Professor Katz has called the erscheinungswiesen of color. This German word means "mode of appearance." Colors may be described as film colors, as bulky colors, as surface colors, etc. Film colors, for example are transluscent and may be superposed upon each other. Bulky colors are luminous and may be illustrated by the color of large masses of materials such as jello in which the color is three dimensional, in contrast to surface color which, as the name implies, is two dimensional and gives its characteristic color because of reflectance. Whoever has worked carefully in mapping the retinal zones of color sensitivity must realize that the zone limits for a 1 degree target which is red, yellow, blue or green will yield a zone of different size and shape than one determined by the use of a 3 degree target. Area is thus an important consideration in the specification of hue, saturation, and brightness. Area, shape and position are factors which may set the stage for contrast, and always are important agents in shaping the total visual pattern.

The laws of color mixture are three in number. The first law states that the mixture of any two complementary hues in the proper proportion will produce gray or achromatic color. If the mixture is in any other proportion the result will be a low saturation of one of the principal components, depending of course, upon the proportion of the two colored lights. The second law states that whenever two or more noncomplementary hues are mixed the result will be a hue whose characteristic will vary with the proportions of the components. The third law states that the

mixture of any two mixtures which produce a gray will also produce a gray.

Using Hering primary color disks (1) 200 mm in diameter and rotating them by means of a 3400 RPM motor, under 1 footcandle of Mazda illumination the first law gave the following result:

194 B ⫽ 166 Y = 200 Bk ⫽ 160 W

208 G ⫽ 133 R ⫽ 19 B = 240 Bk ⫽ 120 W

The above figures are in degrees of arc and represent the size of the Color Sectors made by overlapping the disks. Note that a small amount of B must be added to the mixture of R ⫽ G, because the gray given by these colors alone is yellowish.

When 5 footcandles of illumination was used the results for the first law were as follows:

204 B ⫽ 145 Y ⫽ 11 R = 216 Bk ⫽ 144 W

186 G ⫽ 132 R ⫽ 42 B = 252 Bk ⫽ 108 W

Careful study of these results will show that increasing intensity is accompanied by a change in the composition of the lights reflected from the spinning disks.

The second law was demonstrated by matching the Orange (No. 3), Y-G (No. 7) G-B (No. 11) and B-R (No. 15) as follows:

63 Y ⫽ 297 R = Orange

150 Y ⫽ 210 G = YG

151 B ⫽ 209 G = GB

118 B ⫽ 242 R = BR

For the third law, under 1 footcandle:

118 G ⫽ 76 R ⫽ 83 B ⫽ 81 Y = 218 Bk ⫽ 142 W

At 5 footcandles the match became:

91 G ⫽ 69 R ⫽ 122 B ⫽ 78 Y = 223 Bk ⫽ 137 W

The change in illumination produces changes in the proportions of the components - note for example the increase in the amount of B while all the others diminish with increased Mazda light. This is a very sensitive method for testing equal qualitative or quantitative lighting. Under Fluorescent daylight illumination and under noon north light there is no change in the color match, thus proving that the tubes give a true daylight illumination.

(To be Continued)

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(1) Purchased from the C. H. Stoelting Company, 424 N. Homan Avenue, Chicago, Illinois. Catalog No. 12646, Price per set $2.00.

Demonstrations in
Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

COLOR PHENOMENA
(Part II)

April - 1941 Vol. 2 No. 7

Samuel Renshaw, Ph.D., Ohio State University
with the assistance of Hugh B. McFadden, Ph.D.
Graduate Clinic Foundation and O.E.P. Fellow in Experimental Psychology,
Ohio State University

This paper is a continuation of the discussion of color vision begun last month. We shall consider the question of the proper description of the color of an object, and of the measurement and detection of limited color vision - protanopia, in which the green is weak or absent; deuteranopia or red blindness, and tritanopia or blue blindness or total color blindness.

The most reliable surveys show that about 8% of the adult male population and about 1/4 of 1% of females have some degree of anomalous color vision.

The detection and diagnosis of limited color discrimination capacity is not only important in certain of the military, industrial and artistic vocations but it should be regarded by every optometrist as one of the important parts of a complete and perfect eye examination. Rule of thumb methods must fail in this work as they do everywhere else. The obligation for a considerable understanding of color and color phenomena is doubly emphasized in view of the literature in this field, which almost every leading authority agrees is confused and generally unsatisfactory. This state of affairs is slowly being remedied, and research is helping to bring under harmonious laws the divergent aspects of the problem in which so many branches of science, art and technology have interests.

When I look at a leaf and say, "This leaf is green" the language response merely indicates that I have assigned the very complex series of electrochemical events in my eye, brain and muscles to a specific and arbitrarily standardized classification 'Green' is a symbolic linguistic response just as I may make when I hear a tone and say "this is f#." Color naming is a classificatory type of response, given to a qualitative perception in an observer which enables him to <u>communicate</u> his experience to others. Certain primitive languages contain no word for blue, for example. And even among ourselves, if you and I look out of the window and a trained artist looks at the same scene and we all try to count the <u>number</u> of different <u>greens</u> we can see, we shall probably get four or five while the artist may report that he sees twenty kinds of greens. How shall we regard and describe the color of an object?

If a beam of 'white' light is divided and the path of one half is slightly lengthened and the two halves are then brought together again, a series of dark bands will be seen. These are interference bands. They resemble the nodes in an organ pipe where sound waves of differing wave-lengths interfere with one another.

If light were a stream of particles or 'corpuscles' the reinforcement at the points of interference can hardly be conceived to produce the nullifying effect seen in interferometry. Light, like sound, is regarded as a form of wave mechanics in radiant electromagnetic energy. Some notion of the energy involved has been given in previous papers. Last month it was shown that some wave lengths when mixed with other wave lengths produce an achromatic 'color' -gray. Hues which thus mix to produce gray are called complementary colors. Physically red, green and blue-violet lights are primaries because in various appropriate mixtures they can produce all the visible spectral hues.

If I look at the landscape through a piece of red glass, the glass is said to be red because it transmits only the red rays. 'White' light falls upon it, consisting of red, green and blue-violet lights, but the glass transmits only the red. The green and blue-violet rays are absorbed or stopped by the glass, which thus acts as a selective filter for the reds. Some glasses may absorb 96% and transmit 4% of the green and others may absorb 60% and transmit 40% of the green.

Before me lies a book with a bright red cover. 'White' sunlight is falling upon it. But the surface reflects only the red rays. Thus we call "red" anything which absorbs the green and blue-violet light. Note that a moment ago we said that "red" designates a particular form of human experience. Objects themselves therefore are not colored. But objects do absorb and reflect wave lengths which our detectors pick up and classify. We must avoid the error of ascribing to objects the properties and attributes which they themselves could not possibly possess. Color is a psychological datum. In physics <u>all lights</u> are <u>colorless</u>.

The proper understanding of color is greatly facilitated by forming the habit of regarding a red object, not as one which transmits or reflects only red, but as one which absorbs the green and blue-violet components in 'white' light.

We may state that

Blue = White <u>minus</u> green and blue-violet.

Similarly yellow is white minus blue; green is white minus red and blue-violet.

The color of an object is thus specified without reference to the composition of the incident light. This is important for scientific color work, because the absorption spectrum really specifies the composition of the ray sheaf reaching the eye.

If I look at the same red book under mercury-vapor illumination (a Cooper-Hewitt M tube) the book now looks black. The light from this source contains no red. It does contain green and blue-violet. But since these are absorbed and since there is no red to be reflected, the defining procedure sketched above still holds. The yellowish red paper covering cut film in the photographic dark room looks gray under ruby light. Textures may absorb some but not others of the red rays, in this case the reds, greens and blues are all absorbed leaving a small amount of achromatic light reflected. The relationship of absorption and reflection is reciprocal. The light absorbed by an object is complementary to that reflected by this object.

Few if any objects give perfect absorption or reflectance. That is to say that very few "pure" colors are ever found, unless artificially produced. For example the primary blue of the Hering series of colored papers upon spectrophotometric analysis gave the following reflection spectrum:

Color	Wave Length	Percent Reflectance
Red	660	2.89
Orange	615	2.48
Yellow	585	5.62
Green	530	12.16
Blue	465	76.82
	Total	99.97

Not long ago I had occasion to examine a set of so-called therapeutic filters, sol[d] to optometrists and others, with the clai[m] of the maker that the red filter produced a stimulating or excitatory physiological effect and the green filter a subduing, inhibitory effect. The spectrophotometri[c] analysis of the green glass showed, among other things, that it actually transmitted slightly more red light than the red filter itself! The eye cannot be trusted as an analyzing organ and cannot specify the components in any mixture of hues.

Authorities are agreed that no visible color is warm, cold, beautiful, ugly, exciting, subduing, or intrinsically possessed of any other such property. There is no scientific evidence that any visible hue can or does produce any definite and unvarying alteration of metabolism, digestion, respiration, circulation, ovulation, etc., or any specific emotional, affective or other psychological state. The extra-spectral wave lengths (infra-red and ultra-violet) are a different case. In the UV, for example,

Coblentz and associates at the Bureau of Standards have shown that the germicidal power of this light is quite lethal at one wave length while an adjacent band, only a few Angstroms removed in the spectrum is of low potency.

For those of you who have been reading the able and interesting papers on Visual Fields by Drs. Webb and Brombach I need not argue for the necessity of a careful perimetry in many of the cases you meet in daily practice. Along with the careful delineation of the zones of color sensitivity every good optometrist should be skilled in the analysis of monocular and binocular color discrimination. How shall this be done? What instruments and procedures shall be used?

There are many kinds of "tests for color blindness," good, bad and indifferent. In general there are three classes of such "tests": the spectrophotometric, the projection and the pseudo-isochromatic diagrams or confusion-color methods.

Without doubt the best method is to plot the patient's visibility curve at each 10 mu mu from 400 to 700, using a constant deviation type spectrophotometer or anomaloscope. In the eyepiece is a split field. In one half a color of specified wave length and brightness is set and the patient or the examiner sets or adjusts the instrument so that the other half of the field gives the best possible match, and a reading is taken. This is continued across the spectrum and is repeated for the other eye. Values may be taken at one or several levels of illumination. These data are then plotted and compared to the performance of a normal eye under the same conditions. The Nagel anomaloscope presents a pair of collimators and by a suitable arrangement of lenses and prisms a mixing-matching test field is presented to the observer.

The work with these instruments is time consuming, the instruments are quite expensive but the result is true and precise provided the instrument is properly used. A limiting or an average error method is usually used - a weak psychometric method - whereas if a constant process or a paired comparison procedure is undertaken the time for a test becomes quite large and so this best way is hardly suitable for routine office procedure and must remain for the "grief" and research cases.

The Hering box, familiar to some of you, is sometimes used. It employs a similar mixing-matching method, but the instrument is difficult to calibrate and can give only a comparatively limited statement of the whole hye visibility range.

Houstoun has used a variable blur method by means of a wide field low power microscope which focuses pairs of transparent color patches to be identified. The focal length of the lens system is taken as the measure of color discrimination efficiency.

The projection method is utilized in several tests for color vision. The Eldridge-Green lantern is a sample. The Westcott slide may be cited as another example of this method. This is a standard size lantern slide plate, bearing 40 colored squares arranged in four rows beneath the three standard color squares at the top. These are Green (A) Rose (B) and Red (C). Each of the 40 squares bears a number. The slide is thrown upon a screen and the observer is required to write down the numbers of the color squares which match or closely resemble to test patch A. The same procedure is repeated for B and C. From 1 to several hundred individuals can be tested simultaneously. For surveys or rough screening the test is useful but it does not yield a measure of the amount and kind of color vision anomaly. By means of a set of suitable absorbing filters placed over the slide or in front of the objective of the lantern the whole plate can be shown as it would appear to a red blind, a green blind or to a violet blind individual.

The Ishihara test represents the third type, and this is one of the most widely known and used tests. It consists of 16 colored plates arranged in a 'book'. The plates are colored dot patterns in which different hues are arranged to form numbers which the observer must call out correctly. If he suffers impaired color vision he will see different numbers from those seen by normals on the same plates.

Stilling in 1883 produced the first of these tests, more recently modified and improved by Hertel (1926). Others

similarly have been designed by Grossmann (1888), Oguchi (1914), Eldridge-Green (1920) Schaaff (1927) and Nagel (1906).

The disadvantages of the Ishihara tests are several. The dyes or inks are pastel shades and fade easily if exposed to light or by mere ageing. Coaching and malingering is hard to prevent. The whole series of plates was once printed in the Sunday Color supplement of a metropolitan paper. The test may fail some who have no difficulty with higher saturations, such as are seen in traffic lights, railway semaphores, ship s signal, etc. It does not differentiate the color anomaly satisfactorily. At best it is a coarse screen and the final rejection of pilots, locomotive engineers, etc., on failure to pass this test alone is a hazardous decision to justify.

The Nagel Farbentafeln consists of two sets of color plates and has been very useful for detecting persons who have even slight green or red deficiencies. I have noted that it differentiates persons who pass the Holmgren or Ishihara successfully.

The Holmgren yarns are widely known and used. There are 125 small skeins of yarns of different hues and three larger test skeins - green, rose and red. The observer is asked to quickly sort out all skeins which are of the same general color as each of the test skeins separately, beginning with the green, then the red, then the rose. The small skeins are marked with numbered metal tags which permit identification. When all the test skeins are spread out upon a gray cloth upon a table top and they are viewed through a piece of ruby glass, only their relative brightness will be visible. The skeins appear as they would to a totally color blind person. Much amusement is occasioned by asking someone to match the test skeins while looking through the red filter. The mistakes he makes will usually be like those of the color blind undertaker who is said to have draped a casket with red silk believing that it was gray.

The Westcott, Holmgren, Ishihara and Nagel Farbentafeln can be purchased for an outlay of about $25 00 Together they provide sufficient equipment for the detection, in the hands of a skilled person, of color deficiency serious enough to lead to rejection in certain military or industrial and artistic fields. For exact specification, of course, the spectrophotometer or anomaloscope is the thing.

Now a word about the use of color tests. In spite of the accuracy of the first type of instruments described above, there is much to be said of those tests which permit the skilled and knowing examiner to observe the manner, speed, hesitancy, etc., with which the subject selects or names a color. The analysis of the significance of the mistakes he makes, the checking or consistency repeats, confusion trials, etc., not only help to forestall the results of coaching or malingering but yield a most valuable diagnostic datum for the skilled examiner.

The customary classification of color deficients as protanopes (green blind), deuteranopes (red blind) and tritanopes (blue blind) is not very satisfactory because persons deviate from normal color vision in degree, not in kind. Typological classifications are arbitrary, and the literature reveals that the above classification was based upon no adequate statistical samplings of the total population. It is better to stick to a simple factual statement of the functional status of the patient's color discrimination ability.

The diagnosis and prognosis of color vision should be based upon perimetry of the zones done under standard conditions, adaptometry, together with a careful assay of the functional status of color discrimination, with due regard for the etiology, hereditary and medical findings, all viewed in the light of the psychological and social demands to be met.

Why should not the professional optometrist be prepared to do competent colorimetric work?

Consider questions like these: "Is this dentist unable to match an artificial tooth with live adjacent teeth because he is color deficient or merely because he is color ignorant?" "How can a red blind person be trained to utilize other bases of discrimination to compensate to the fullest possible extent for his deficiency?" "How much can normal color

vision be extended through training?"

What does it mean when an artist of note recently said, "I never fully and clearly perceived color on my canvas or pallette until a wise teacher urged me to dispense with brushes and paint <u>with my index finger</u>." Only then did the color experience become immediate, empathic. Color is a fascinating field for study. Very much remains to be learned about it.

* * * * * * *

For those who might like the information, the Westcott lantern slide is made and sold by the Central Scientific Company, Chicago, at $5.00 the set. The Holmgren yarns are supplied by C. H. Stoelting Co., 424 N. Homan Ave., Chicago, at $15.00, (Catalog No. 12325). The same Company lists the Ishihara book (No. 12326) at $6.00, and the Nagel Farbentafeln (No. 12327) at $1.75 per set. Complete instructions are furnished with each of these tests.

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REFERENCES

1. Collins, Mary, Color Blindness, 1925.
2. Houstoun, R. A., Vision and Color Vision, 1932.
3. Parsons, J. H., Color Vision, 1924.
4. Parsons, J. H., Introduction to the Theories of Perception, 1930.
5. Abney, Researches on Color Vision and the Trichromatic Theory, 1913.
6. Eldridge-Green, Color Blindness and Color Perception, 1909.
7. Eldridge-Green, Physiology of Vision, 1920.
8. Jennings, Color Vision and Color Blindness, 1905.
9. Nagel, W., Einführung in d. Kenntnis der Farbensinnstörungen und ihre Diagnose, 1908.
10. Troland, L. T., Psychophysiology, 3 Vol., 1930.
11. Bidwell, Curiosities of Light and Sight, 1899.

Demonstrations in
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OPTOMETRIC EXTENSION PROGRAM

AFTER-IMAGE PHENOMENA

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Samuel Renshaw, Ph.D., Ohio State University

After-image phenomena provides us with an interesting and important field for study. To the extent that the retinae can be regarded as a part of the brain on the outside of the body, retinal phenomena, of whatever sort therefore present us the available mechanism for ascertaining facts relating to both peripheral and central vision. In this sense, peripheral means that part of seeing related to the specialized end-organs and central means that part contributed by the brain and the effector organs of the body.

The importance of a better understanding of after-image phenomena is emphasized by the desire to learn as much as we can of the possible relationship between the simple visual after-image and the memory after-image. Beyond the memory after-image we may recognize the eidetic image as differing from the memory image in its high fidelity to detail, form, size, color, position, etc. If it could be determined that the visual after-image is the simple beginning of this whole complex series, then we have provided an ample justification for careful inquiry into the phenomenal properties of the after-image.

The after image, also, is important in that it may serve as a proving ground for the truth and falsity of various theories of color vision. In the later part of this paper some sample experiments will be described which will enable you to observe the properties of the after-image and some of the phenomena which may be examined with respect to their harmony with color theory.

From Helmholtz and Hering to the present time there has been little agreement as to the mechanism of the after-image. Each of the above emphasized certain aspects of positive and negative after-image and passed over others which did not conform so well to the best interests of his own theory. Hering postulated an active autonomous process, opposite in character to the process of excitation as the basis for the negative after-image. Helmholtz, following Goethe and Fechner, considered the passive condition of the retina after stimulation as its basis. The positive after-image still continues to offer difficulties to both theories. Our interest in the controversy simply lies in the fact that a partly erroneous conception of after-image has come to be widely held because of this earlier work. This is the view that the excitatory process continues in the cones and rods for a certain length of time after the termination of a light stimulus and this is said to produce a positive after-image of the stimulating object identical in hue and in contrast of light and dark areas. Next there is recovery from the 'fatigue of excitation' which is unequal in different retinal areas in pattern vision and this produces the negative after-image of complimentary hue to that of stimulus and reversed in intensity values. When the retina recovers completely this signifies that the negative after-image has completely faded because it diminishes in size and its edges become hazy. The process is somewhat slower in the middle of the image.

There have been a number of demonstrations of the inadequacy of this scheme. Katz has explicitly criticized the adaptation assumption and has presented a variety of evidence against it. Jaensch particularly, has described an extended continuity between the immediate after effects of stimulation including in a single series all the stages of after-image, the memory image and the eidetic image. Jaensch has shown, for example, that a visual pattern of a certain intensity will produce a positive after-image if it is of interest to the observer, negative if it is not. McDougall has pointed out that borders graded from the brightness of the figure to the darkness of the ground

constitute a condition favorable for the production of positive after-images; also that the duration of both the positive and the negative phase is about the same under mean conditions; that is, the longer the positive lasts, the longer will be the duration of the negative. He has also demonstrated the production of a positive after-image of unusually long duration from fairly intense stimulations of the dark adapted eye with durations of stimulation subliminal for the production of a negative after-image. This same phenomenon has also been studied by Swindle, and by Dimmick who found that no after-image of a red parafoveal stimulus nor of a white central stimulus of less than foveal size was obtained. Swindle maintains that a positive after-image stage merely precedes the negative if careful fixation has been maintained both during the impression and following impression, thus a loud sound occurring at the termination of the stimulus makes it impossible to see this primary positive stage because according to Swindle, it induces reflex movement of the eyes.

The phenomenon known as the "flight of colors" has been a favorite point on the fatigue assumption. Following stimulation by white light a varied series of color after-image is produced whereas theoretically, these should be achromatic. McDougall has shown that a similar "flight of color" follows when the stimulus is a colored light of any hue. Here the negative after-image should be complementary. Hartman has pointed out that the negative after-image of an ambiguous field with different colored halves changes from one blended color to two separate complementary colors as the perception of the spatial pattern shifts from a single to a double meaning.

The instances are mentioned merely to indicate from the large literature the fact that the concept of the after-image as a "retinal fatigue" or adaptation phenomenon seems to account for many of the observed facts and therefore leaves the proper understanding of mechanism unaccounted for. Later in this paper some after-image phenomena will be shown which do not lend themselves either to the fatigue-adaptation assumption or to the concept that after-images are solely the result of local photochemical processes in the retinal elements. This simply means that there are grounds for reasonable doubt as to whether the simplest and most primary of the after-image phenomena is retinal or cortical or both.

Whenever we stimulate the retina with light and the stimulus is withdrawn after a short period the visual field will have a different appearance in consequence of the preceding stimulation from what it would have had if the latter had been of different intensity or color. This phenomenon is customarily referred to as visual adaptation and adaptation may be regarded as a temporally induced effect in contrast to spatial induction. If the primary stimulation is limited to a definite part of the retina the persisting after effects are called after images.

The nature and course and properties of after-images have been studied largely in relation to the size, hue, intensity, etc., of the stimulating ray and to some extent they have been viewed as dependent upon the brightness, form, etc., of the projection ground. In 1899 Franz studied the relation of size of the stimulus patc and the duration and intensity of the exposure to the induced after-image and its duration. He found that something analogous to the reciprocity law holds in that a reduction in stimulus duration or intensity or size was accompanied by a reduction in the process and duration of th after-image. A much more extended study of these relations was made by Barry and Imus in 1935 in which they showed that the duration of the after-image increases with increased intensities of stimulation and with increased duration of the stimulus up to as long as 60 seconds.

Many observers have shown that if brightness is equated, the wave length of a stimulus has no effect on the duration of the after-image. In peripheral image the duration is shorter. After-image duratic also was found to be greatest in the morr ing when the eyes were fresh and least when the eyes were fatigued from prolonge work at the near point.

Ebbecke in 1929 reported perhaps one of the most carefully made studies on the conditions for producing the after image He proposes, as a result of his work, a theory which assume in the retina not twc opposed after effects, but one effect on

This he called after-excitation.

After a brief flash of light, measured by the reaction time method, Creed and Granit and later Finebloom have shown that the latency of the after-image is generally from two to three seconds. This is longer for intense than for weak stimuli. The latent period is not empty as the observer is partially dark adapted. He can note the primary momentary flash, a second flash and a third weak positive effect followed by a negative after-image, all of which happens within a couple of seconds, as Judd has shown.

Under favorable conditions of stimulation a series of after images may be seen. As many as 9 different after effects have been described by G. E. Mueller but all of these would be seen only in the ideal case. Of these the 3rd (Hering), 5th (Purkinje), 7th, 8th and 9th are after-images. If the stimulus is relatively intense and its background in good contrast the following effects can readily be described; (1) immediately after the stimulus there is a brief formless flash of fairly high intensity usually described as reddish or yellowish regardless of the hue of the stimulus; (2) an image of like chiaroscuro relations and like hue to the stimulus object. This is the positive after-image; (3) an interval of darkness or absence of after- effect lasting a second or two; (4) an image or reverse chiaroscuro relation and hue complimentary to the stimulus object; (6) an irregular fading, disappearance and modification of form comprising an unpredictable series. If the duration of this last series is gradual, shifts in hue take place. Most authorities tend to agree quite closely on the order of these effects. From the 4th stage on there is usually considerable movement or drifting of the after images.

In working with after-images it will be discovered that a certain amount of practice or training is necessary in order to acquire the best observation of these effects. At first it is best to work only in the early morning shortly after arising. Stimulate after partial or complete dark adaptation. Use a series of 8" x 8" squares of light, medium and dark gray, and red, green, blue and yellow as background and prepare 2" x 2" squares of the same material. These can be laid flat on a table and illuminated from a shaded lamp of about 100 to 500 watts. The viewing distance should be about 2 feet. If black and white papers are available include them in the series. Place a small square of white in the center of the 8" square of black, fixate the center of the white patch continuously and without eye movement for 20 seconds. Maintain the same eye posture, extinguish the light and simultaneously cover up the test patch with medium gray. Wait patiently for the after-image to appear and do not be too hasty in assuming that it has run its full course. Following this same procedure use a medium gray ground. Place upon this successively 2" x 2" patches of yellow, green, blue and red. Carefully describe the after images. If this is done several times and you carefully write out your description attempting to specify hue, saturation and brightness, you will note a marked improvement in your observational skill. Try all combinations of test patch and ground.

After dark adaptation in a darkened room look at a 25 or 40 watt frosted mazda lamp for 5 to 20 seconds. Extinguish the light and again without moving the head or eyes, observe carefully the succession of colored after-images and describe these carefully. Write down or dictate the order and duration of each phase and repeat these several times; sometimes when fresh and sometimes after a long hard day. Compare your protocols with respect to points of difference as to duration, intensity, hue, order, etc.

With the aid of an assistant develop an after image of a bright yellow 2" x 2" square on the 8" x 8" black background, for example. Carefully measure the distance from the test patch to your eyes. After 20 seconds of such stimulation project the after image upon a large square of gray cardboard about 24" x 30" You work best if you work in a room where the illumination level is very low, enabling you just to distinguish the form of the gray square. Place the gray cardboard square first at 2 feet, then at 4 feet then at 8 feet from the eyes. Have the assistant measure the total area of the projected after-image. It will be noted that the size of the after-image follows Emmert's Law. This law states that the projection area will be 4 times

as great when the distance is doubled, 9 times as great if the distance is tripled, etc. Repeat the observation this time projecting the after-image to the corner of the room where the wall meets the ceiling. Note that the image tends to take the shape of the projection ground. Set the gray cardboard square about 8 feet from the eyes and between the eyes and this square interpose a similar-sized white square in the center of which has been cut a diamond shaped aperture whose dimensions are about 6" x 6". Try to project the after-image through the hole in the first square onto the rear gray square. Also try changing the distance, shape and size of the apperture in the intermediate screen.

For work with transmitted light a light tight box should be constructed with a hinged front. Place a strong light inside this box. Arrange a suitable window in the front of the box so that pieces of colored glass, papers, etc., can be trans-illuminated. Cut from a square of black cardboard 4 slots as indicated in Figure I.

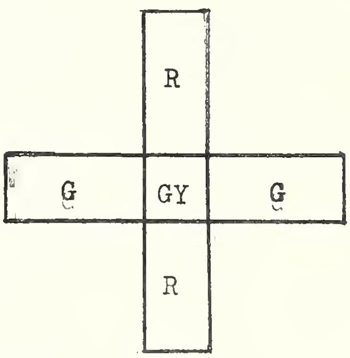

Fig. 1

The upper and lower members should be covered with red paper, the left and right members should be covered with green paper. The small central area should be covered with a piece of light gray. Develop an after-image from the light transmitted through this figure. Report the observation several times describing carefully what you see. Now reverse the test object so that the left-right members are now in the top-bottom position and report the observation. This is done in order to convince you that the effect noted must be ascribed to the retinal-cortical mechanism and not to the hues of the members in the stimulus patch.

Prepare a transparency similar to Figure II below.

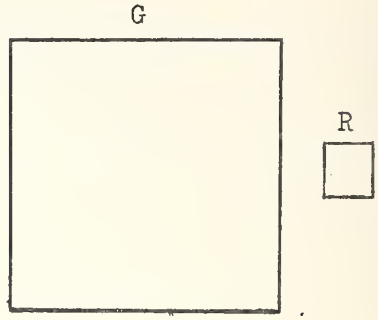

Fig. 2

The larger green square should be about 35 mm on a side, and the smaller red squ 5 mm x 5 mm. The small square is separated from the larger one by 5 mm. Fixa the center of the larger square 20 secon and describe the after-image; after exti guishing the light and projecting upon a gray screen at the same distance. Now fi ate the center of the smaller red square and repeat the observation. Repeat this with the small square in the R. L. above and below positions.

Make another transparency of the same ma terials like Figure III.

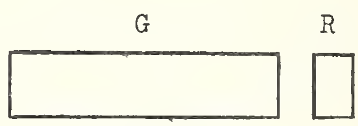

Fig. 3

In making transparent figures, colored papers, gelatins or glass can be placed over suitable appertures cut in stiff black cardboard or thin metal.

Take two 8" squares of saturated green paper and place them side by side on a neutral gray ground so that a vertical gray strip about 1/2" wide is visible between them. Fixate on the middle of the gray strip with the eyes about 15 inches from the paper for 20 seconds in ordinar day light. Now look about the room and

note that on whatever ground you look such as the walls, floor, chairs, etc., you will see a narrow green strip. Note that a reddish hue is induced in the gray strip during fixation and that the green strip after-image can be accounted for as the complementary after effect of the induced red. Regions eccentric to the maculae, however, which have been stimulated by the large green squares do not develop red after-images. Try to develop a certain explanation of the total suppression of the green field in this experiment.

Finally, I should like to suggest a most interesting field for study: - after-image phenomena produced by stereograms in color. Recently I have shown that by the control of figure-ground relations in the stimulus-perceptual field third dimensional effects can be completedly suppressed. By other arrangements they may be brought out clearly. Start with line-drawn geometric figures which make relatively simple shapes. At first try placing these in one hue upon an undifferentiated background of the complementary hue. Make another series in which black, white or gray stands between the figure and its ground. Surround the figure with a moderately heavy black circle slightly larger than the figure. You will observe some very thought provoking things.

ERRATA

In the April paper on Color Phenomena, Part II, the definitions of the terms protanopia and deuteranopia were reversed. Protanopia means a limitation of visibility in the red portion of the spectrum. Deuteranopia means a limitation of visibility for the green portion of the spectrum. This correction is made in the interests of accuracy of statement. It should be emphasized, however, that such classifications of anomalous color vision do not satisfactorily fit the facts.

The relative question is the determination of the amount of variation from the normal visibility for the spectral hues and not the arrangement of persons into a typological classification which is rarely seen in actual cases.

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OPTOMETRIC EXTENSION PROGRAM

THE SKIN

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Samuel Renshaw, Ph. D.
Ohio State University.

Extensity is an attribute of all visual and of all haptic experiences. In order to understand, in simplest and clearest terms, the visual space world we start with the skin.

The reason we begin with the skin is because a large amount of the visual discrimination of position, size, distance, movement, etc. derives from cutaneous, kinaesthetic and motor sources. These components are often wrongly ascribed to vision. Later in this paper we shall describe some simple experiments by means of which you may demonstrate the important role played by the skin in space discrimination.

Psychologically space is originally derived from sight and pressure. With increased age and experience these two functions become fused or blended so that they tend to become more and more interdependent. In physics and geometry there is but a single space and this always and everywhere the same. In psychology there are four spaces: the two dimensional fields of the skin and the resting eye, and the three dimensional spaces of active touch and the moving double eye.

From this point of view the last statement is entirely too conservative. The spaces yielded by the finger, the lips, and the skin of the shoulder blade are three different things. The space of foveal vision is not the space of peripheral vision. Further complication of the problem arises from the fact that fineness of discrimination in any region of the skin can be greatly extended and improved through appropriate training procedures. This must mean that space is an achievement. We learned to construct our world of space discriminations in terms of the consummatory acts and not in terms alone of the patterns of impression which reach our sense organs. The skin becomes increasingly important for students of vision when we understand that it is not only the most extensive of all the sensory surfaces but that practically all of the sensory functions have been developed from it. It includes not only the integumentary covering of the body but also the red area of the lips, the lining of the cavities of the mouth and nose, and the conjunctiva and cornea of the eye. Thus every postural adjustment of the visual receptor involves a component of cutaneous stimulation.

Our knowledge of the skin and its functions is still incomplete. About 50 years ago Blix in Sweden, Von Frey in Germany and Donaldson in America independently discovered that the skin, like the retina, presents a distribution of punctiform sensitive points. When the threshhold for pressure is studied by carefully exploring a unit area of some skin surface great differences are found. If a horse hair about two inches long is fixed to a match stick with a drop of sealing wax and is pressed down on one pan of a precision balance a series of such hairs can be found and calibrated which will just bend when the weight of one mg. is placed in the other pan, and at the other extreme one can be found which will raise 200 times as much. Another method is the use of a limen gauge by which the pressure which must be exerted to just perceptibly be discriminated is measured by the amount of energy stored in a small coiled spring. On the tip of the tongue, pressure of 2 gms. per square mm. is the approximate threshhold value. On the tip of the finger this is about 3 gms., on the back of the finger 5 gms., on the back of the hand 12 gms., on the calf of the leg 16 gms., on the abdomen 26 gms., on the back of the forearm 33 gms., on the loin 43 gms., and on the thick parts of the sole of the foot 250 gms. Von Frey showed that for pain a pressure of 0.2 gms per square mm. on the cornea would produce

pain. Areas on the back of the hand require a pressure of 100 gms. If a square cm. is carefully explored on the tip of the nose the following distribution of sensitive points has been found:

Pain	Pressure	Cold	Warm
44	100	13	1

On the back of the hand the figures are:

Pain	Pressure	Cold	Warm
188	14	7	0.5

These examples are given to show the unevenness of distribution of sensitive spots in the skin. If an area of one square cm. is thus carefully explored and a map is made indicating the position of the sensitive points and this is done repeatedly for the same area no two of the maps will look alike. This means that on two successive days the number and spatial distribution of sensitive points does not remain fixed. In one famous experiment (Dallenbach, 1927), the sensitive spots were carefully mapped a considerable number of times and those points located which gave a qualitative report 100% of the time. The square cm. of skin was then surgically removed and carefully stained and sectioned histologically. It was then examined under the microscope to see what types of specialized nerve endings could be found to correspond with the sensory qualities yielded by the various spots. The results of this examination showed first, the presence of almost no specialized nerve endings and second, almost no relation of the position of the dendrites in relation to the sensitive points.

Facts such as the above take on a great importance when we consider them in relation to the fundamental problem of cutaneous and visual space. The resolving power of the skin or retina is exhibited by the ability of an observer to be able to report one or two points when the stimulus is a part of points with small separation. Secure a small drawing compass and grind the points until they are fairly blunt. Set the points about 6 mm. apart and starting at the tip of the middle finger with equal pressure draw them slowly over the finger across the palm, the wrist, the forearm, the elbow and stop about the middle of the biceps. Do this several times and observe that for a fixed distance between the two points they seem to approach each other until they seem like a single line at some positions and to diverge widely at others. Start with the same separation at the edge of the lips and pass slowly around the cheek beneath the ear to the middle of the back of the neck. It becomes obvious that when two points on the skin are stimulated whether we feel them as one or as two is determined only in part by the actual separation of the two points and in part by the region of the skin stimulated. From the best neurological sources the subcutaneous network of nerve receptors in a region of high threshhold does not diffe materially from that in a region of low threshhold. It must therefore follow that the discrimination of twoness is a psychological function because it can be demonstrated that regions of low spatial sensi tivity can be formed into regions of high spatial sensitivity if appropriate training methods are used.

If various regions of the skin of the hand and forearm are explored for the two point threshhold, it will be found that the thres hold will be smaller, the greater the curvature of the skin surface. On a flat sur face such as the volar forearm midway between the wrist and elbow the limen will be found to be several times larger than in those regions where the skin surface shows greater curvature. There are severa methods which may be employed in determining the least perceptible separation of tw points to be perceived as two. One of the most accurate of these is the method known as the constant process method or the meth of constant stimuli, where a series of sep arations varying in small degree is arbitrarily selected. Each of these is carefully applied to the same region of the skin 100 times. The subject is required to report whether he feels one or two poin When the observations are all completed, you have two columns of figures: one indicating the actual separations in mm. of the points and another indicating the per cent of <u>two</u> judgements When these are plotted with the separations on the abscissa and the percent of positive judgements on the ordinates, they should yield an S-shaped or ogive curve. The point at which one can judge the stimulus correctly half of the time is conventionally regarded as the threshhold. Students invariably report difficulty in determining the threshhold for two points because there is always present a marked practice effect, the influence of which is to produce more

nd more positive judgments with increasngly less separation. If a limiting method s used one starts with smaller separations nd gradually increases them until the judgents become consistently two. The procecure is then reversed by starting with a arge separation and gradually reducing this ntil the judgments become consistently ne. If this is done carefully, it will be ound that the threshhold yielded by the scending procedure will not be the same as hat secured by the descending procedure. he common practice is to list the boundries of this range and take the midpoint s the value of the threshhold.

reat care must be exercised so that the wo points reach the skin at the same intant in time and with identical pressures. therwise the judgment will be in error ecause in this case it will be formed on he basis of successive rather than simultaneous stimulation.

t is known that if a single point and ater another point, slightly removed in pace, is stimulated, the relative separaion of the two points will be a function f the time and intensity relations of the wo stimuli. If we assume that the actual eparation is 20 mm. and the second point s stimulated one second after the first ut with twice the intensity, the first oint will seem nearer to the second one. t is easy to demonstrate the phenomenon hich Helson has called the Tau effect. elect a flat surface on the volar forerm and stimulate point A about 2 inches elow the elbow, two seconds later stimlate point B with the same pressure 60 mm. oward the wrist, and four seconds later timulate point C 30 mm. farther toward he wrist. Let A, B, and C lie on the same traight line. After these three stimuli ave been applied, take a pencil and make three dots on a sheet of paper representng the phenomenal distances which separate hese points. Measure them carefully and ompare them to the actual separations. It will be noted that with intensity kept onstant, it is possible by changing the iming to produce the same effect as if you changed spatial separation. This finding is of great importance for it inlicates that in experience, time, intensity and space all cooperate in the production of the ultimate phenomenal discrimination. If this experiment is repeated varying the factors of time, intensity, and spatial separation of the three points, you may lemonstrate the essential truth of the interrelations of these variables. The studies on the problem of localization have been fruitful in teaching us many things about the genesis of tactual and visual space. In one of the papers last year a series of experiments were described in which localization of points stimulated upon the skin by children and adults were compared. A differentiating experiment was made in which the tactual localization of congenitally blind children and adults was compared with that of seeing children and adults. The ability to localize a point stimulated is highly important as a factor in the correct perception of form and pattern.

From a flat sheet of soft thin copper, cut out a series of small forms such as aquares, triangles, stars, crosses and similar shapes. Let them vary in total area as well as in shape. With the subject blindfolded, place these on various skin surfaces such as the volar forearm, the back of the hand, the palm, the tip of the finger, the center of the check and etc., and press them gently but firmly into the skin with the tip of a lead pencil or small tweezers. The subject, of course, is blindfolded and is requested to describe or to draw the shape and size of the perceived figure.

These simple demonstrations should give you an introduction to the tremendously interesting and important investigation of the sense-perceptual field afforded by the skin. This field is of primary importance for all persons who are ultimately interested in gaining a complete understanding of visual phenomena. The skin provides for us a ready means of studying the fundamental concept of extensity in relatively simple form. Visual extensity is not materially different. The conviction of the essential unity of the senses will grow more and more strong as these observations are extended and it will become increasingly clear that perception is essentially a unified process regardless of the sense modalities which contribute to it.

Finally it should be pointed out that in certain types of anomalous vision, the examination of the spatial sensitivity of homolateral skin areas becomes a most useful diagnostic adjunct. This is in line with the general view that the perfect eye examination of the future will not stop with differential procedures of measuring various aspects of vision alone. The ultimate answer to some of these problems will have to be sought in such functions as those which we have made the topic of our present discussion.

Demonstrations in

Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

THE VISUAL THIRD DIMENSION

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Samuel Renshaw, Ph.D.
Ohio State University

For more than two centuries the problem of stereopsis has been a puzzling one. Today the answers to many questions relating to the visual third dimension are still unknown. The basic problem is: When two differing patterns are presented to the two eyes under appropriate conditions, what is the mechanism which produces fusion and tridimensionality?

It shall be the purpose of this paper to provide some simple demonstrations of the principles involved in seeing in three dimensions. It is not necessary to justify the importance of a clear understanding of these principles. Look at the twenty-one things you do in the analytical examination. Count the number of them which involve the visual discrimination of depth and distance where both monocular and binocular parallax is indicated. It is safe to say that future research in optometry will have to deal seriously with these problems. The importance of the dynamic interrelations of accomdation and convergence have repeatedly been pointed out to you. Both functions are intricately related in stereoscopic vision.

Before we begin our series of experiments, let us look briefly at the existing theories. I know of at least five which have been proposed to account for three dimensional vision. (1) The first of these begins with Berkely in 1709. It holds that depth and distance are generated out of the kinaesthetic sensations from the acts of accomodation and convergence. These afferent impulses form the context for the visual sensations issuing from the excitation of the retina. The "meaning" of depth comes from them. Presumably the manner in which this latter function occurs is simply to be regarded as similar to any other cue process. The sensory impulses arising from the posture regulating mechanisms, from the lens, the eye lids and the extrinsic and intrinsic muscles furnish differential sensory patterns and the responses to these patterns are either natively or empirically defined in terms of depth experiences.

A little reflection will show the obvious difficulty with such a theory. It involves the principle of a degree of specificity in the sensory signals for producing precisely discrete responses which Koffka and others have shown does not and cannot exist. Nevertheless, this theory has had widespread dissemination. It seems to have become the favorite one of physiologists and of many other writers. It is an easy if not a satisfactory solution to the problem. (2) The second theory is based on the principle of retinal image disparity. When the optic conditions for stereopsis are fulfilled the two images will not superpose. There is always parallax but fusion does take place. Consequently it is presumed that depth discrimination is a direct function of the amount and direction of the disparation of two images. Fusion is accordingly a compromise between seeing doubly and seeing singly. The brain is supposed to do the compromising. The net result of the compromise is the production of a new quality, namely the third dimension. There are many unsatisfactory things about this theory. We shall not go into them here. (3) A third theory holds that depth originates from a series of secondary criteria: such things as chiaroscuro, interposition, height in the field, etc. The ancient Chinese artists, for example, met the difficulty of producing depth in their drawings, paintings and etchings on two dimensional surfaces by the simple expedient of height in the field. The principal difficulty with such a theory is that it solves the problem by restating it. If we are willing to grant

that depth is produced by the operation of these so called secondary criteria and ask how do they produce the third dimension, the answer is not forthcoming. (4) In the last quarter century, the theory of isomorphism has been advanced. This theory presupposes that the projection of the pattern of excitation on the retina spreads out into a third dimensional pattern of electro-chemical energy distribution in the brain. Whenever certain brain areas are active in three dimensional space under specific conditions, then a three dimensional discrimination parallels or accompanies this process. It is not our function here to do more than merely state a few representative examples of the theoretical attempts that have been made to systemize thinking regarding this problem. However, in considering this theory, it should be noted that the theory is wholly limited to neurological operations and derives from an attempt to formulate an explanation of visual depth on the basis of potential gradients and the rate of electrical leakage in the adjacent regions of low and high activity in the brain. (5) In addition to the above I have tried in a sort of amateurish fashion to formulate a theory which might serve as an adequate working basis for the study of these phenomena. This theory has its essential roots in what I choose to call motor theory. It begins with the detailed consideration of figure-ground structuring. It presupposes that like the skin the moving double eye discriminates the visual third dimension as an intricate skill which involves much more than purely visual considerations. The limitations of space will not permit further exposition of this view here.

It is perhaps wise in attacking a problem of this sort to proceed inductively. This means that we begin with a precise description of what happens and of all of the conditions under which these happenings take place. As these descriptions accumulate, we may discover in them common principles. These may lend themselves to generalizations or to mathematical expression. When such a body of facts becomes elaborate enough and detailed enough, we may then formulate hypotheses which may eventually develop into a theory but clearly first much work must be done, much careful thinking and experimentation.

Let us begin with a demonstration of Scheiner's famous experiment. This was first published in 1619. It is interesting for three reasons. It brings the mechanism of accommodation into direct comparison with the action of lenses and screens that we are familiar with in optical instruments. It illustrates the laws of double images seen by a single eye and finally it emphasizes in an instructive way the fact of the inversion of the retinal image. Titchener describes the experiment as follows: In a card, with a needle, make two fine smooth holes one mm. (or any distance less than the diameter of the pupil) apart. Mount two kitchen matches on No. 5 corks with the heads upright. The observer sits with his back to a window; one eye is hooded, a black cloth screen stands on a table before him about 75 cm. away. The card is held up close to the open eye, the pinholes horizontal. The corks are set up along the line of sight at distances of 20 and 50 cm. from the eye respectively.

If now the observer looks at either match, it is seen singly and sharply outlined, but if he looks at the nearer match the farther one is indistinct and double; if he looks at the farther one, the nearer is indistinct and double. Moreover: if one of the pin holes be covered (by another card or by a finger) while either match is being fixated, there is no change in the image of that match; the whole field is simply made somewhat darker. There is a change, however, in the double images of the match which is not fixated. If the observer looks at the nearer match and the left pin-hole is covered, the left hand single image of the farther match disappears. The double images are same-sighted, or 'uncrossed'. If on the other hand he looks at the farther match and the left pin-hole is covered, the right hand single image of the nearer match disappears. The double images in this case are different-sighted, or 'crossed'. Discuss and explain the shifting of the three images with differences of arrangement of the pin-holes. Draw a simple diagram of a meniscus lens back of which is the card containing the pin-holes and back of this place a point which represents the retina. In front of the lens at appropriate distances place lines to represent the matche Draw in the lines representing the ray sheaf. Designate the various points by letters and see if you can write out from this diagram a complete explanation of wha Scheiner's experiment teaches you about the phenomenon of accommodation in the single eye.

The next and last two papers in this series will present a series of stereograms which will enable you to build up step by step some important generalizations regarding the manner in which we perceive things as three dimensional objects. As a preliminary to this, it is necessary to make one further demonstration. Secure a cigar box or supply of stiff black cardboard and some black photographic Scotch tape preferably about 3/4 inches wide. Also secure two small mirrors. These should be of thin good glass preferably silvered on the anterior surface. Follow the diagram below and construct a box such as that illustrated.

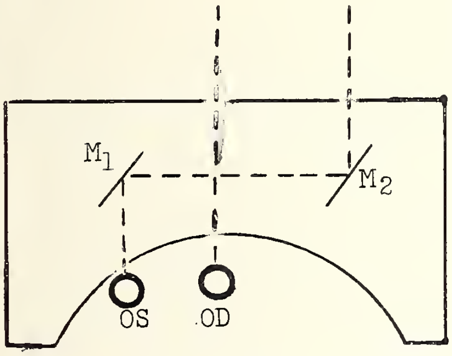

Figure 1.

Be sure that the two mirrors are set in parallel and note that the right eye looks directly through the front and rear apertures without any interruption. Note also that the purpose of the two mirrors essentially is to transpose the left eye to a position to the right of the right eye so that with the aid of this instrument, it is possible for one to wear the instrument and observe what happens to the discrimination of the visual space world when we have radically changed the convergence patterns and the eye movement patterns of the two eyes. If care is taken in constructing the instrument, a single piece of elastic around the head will enable you to wear it without discomfort for one or more hours. If you will do this and attempt to judge sizes, positions and distances of objects you will find it interesting and instructive. Notice the effect of wearing the instrument while sitting at a table or workbench where you customarily use the tools of your profession. Describe in detail and record accurately all of the observations that you make for this instrument. Look up in the literature the description of various other types of psuedoscopes. How does this little instrument differ from conventional types of psuedoscopes? By a slightly different arrangement and with the aid of two additional mirrors you may prepare a telestereoscope. The diagram in Figure 2 illustrates the principle of this instrument.

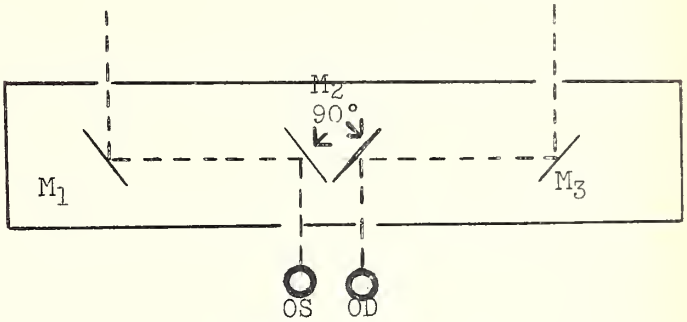

Figure 2.

It can be constructed quickly and cheaply. Its function is to give to an individual a virtual extension of the interocular distance. Make one of these and examine the distant landscape as well as nearer objects in the room. Set down on paper, looking through the instrument, your guess as to what the effect would be when you increase your P.D. to 1 1/2, 2 and then 4 times your normal P.D. How do you account for the discrepancy between theory and observation in this case?

Demonstrations in
Psychological Optics

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OPTOMETRIC EXTENSION PROGRAM

STEREOPSIS I.

August - 1941 Vol. 2 No. 11

Samuel Renshaw, Ph. D.
Ohio State University

In this paper and in the one following which will conclude our series, we shall try some experiments which represent a continuation of the subject matter of the last two papers.

The general object of these demonstrations is to provide instances which exhibit the basic conditions for stereoscopic fusion so far as the test object is concerned. It is assumed that the figures will be drawn on white cardboard (3 1/2" x 7") and that the centers of the figures are separated by approximately 70 mm. When such figures are viewed through five diopter spheres arranged as if they were base-out-prisms, the correct focal distance of the stereogram for best possible fusion of identical points (for the emmetropic eye) will be 147 mm.

If the observer's eyes show excess phorias, then the stereograms must be viewed through appropriate prisms to insure that the above conditions are fulfilled.

It is hoped that each of you will take the time and trouble to construct the following series of stereograms for yourself for the reason that it will give you a more adequate appreciation of the forms and the geometric principles involved and it will permit you to introduce checking variations which become highly important in the synthesis of the deductions and generalizations which should arise from careful observation.

Most well-stocked photographic dealers sell at low cost, packages of blank stereogram cards upon which drawings and photographs may be made or mounted. Draw a vertical midline which separates a card in two symmetrical halves. Stereogram No. 1 is to be made as follows: In the left hand portion of the card there are two black dots. These dots are 2 mm. in diameter. Both are located on a mid-horizontal line. The centers of this left hand pair are separated by 5 mm. Thus the left hand dot is 37 mm. from the vertical midline and the right hand one of the pair is 32 mm. from the midline. In the right hand half of the card, there are also two dots of the same size and also placed on the horizontal midline. These dots are separated 3 1/2 mm. apart from center to center, the left hand one of the pair being 33 mm. from the midline and the right hand one 36 1/2 mm.

If this stereogram is viewed under the conditions stated above, it will be noted that two dots will be seen, the right hand one smaller and nearer to the observer, and standing in front of the plane of the card. If the card is now inserted in the stereoscope up-side-down, then the reverse condition obtains, namely - the left hand dot appears smaller and nearer. This slide illustrates a fundamental condition for stereoscopic fusion. The two images to the right and left eyes cannot be superposed geometrically. If they were and the left hand members of each pair were brought into superposition, then obviously three dots would be seen. In such a case either there is a complete suppression and foreshortening of one or the other of the two right hand dots; or else fusion means that some kind of 'compromise (probably in the brain) has taken place. How can we test these assumptions?

Make up a second stereogram of the same general design substituting circles 4 mm. in diameter for the dots with the left hand pair 14 mm. separated center to center, and the right hand pair 21 mm. center to center. With a fine pen, draw in about one-half dozen parallel lines in the right hand circle of the left hand pair and make these lines slightly oblique, running from upper right to lower left. In the right hand member of the right hand pair make the lines oblique from the upper left to the lower right. The object of this figure is to show at once whether fusion takes place or not between the right hand members of the two pairs of circles. The interior lines of these circles provide the customary condition for rivalry. If rivalry is observed then clearly no fusion has taken place, and if no

fusion occurs, then will we be able to observe depth and foreshortening?

A second similar slide should be prepared, this time carefully lettering a block F on the left and a block L on the right. If now fusion takes place, these two letters will combine to make the customary E. All of these experiments are designed for a single purpose, namely, to show clearly and unambiguously what happens within the figure when stereoscopic fusion takes place.

It is wise to put in writing a complete description of everything you observe and to draw such generalizations at this point as seem to be warranted by the facts. Effort should be made to do this as carefully and exhaustively as possible. Additional slides can be made in which the disparation of the dots and circles is both diminished and increased and the effects upon fusion noted. It is instructive to do this, and to compare the result with systematic variation of P.D. at the eye openings.

The question naturally arises: Are these observed effects a consequence of the stimulation of relatively small retinal points or do they hold for other types of figures? Does shape of figure, position on the retinae, disparation, relative size, etc., determine fusion? In order to test this hypothesis, prepare stereogram No. 4. In the same spatial orientation as that given for stereogram No. 1 above, draw two pairs of parallel lines with the same disparations as given for the dot pairs in No. 1. Make these lines about 1/2 mm. wide and 26 mm. long. Examine this figure in the stereoscope and carefully describe what you see. Turn it upside down as before and note that the change from right to left introduces no important new variation. In the first case the right hand line appears to stand out from the plane of the card and is distinctively shorter than the left hand member. If it could be established that the degree of foreshortening in the right hand member is a precise function of the degree of stereopsis, and if a suitable means of measuring the amount of this foreshortening could be devised, we should then have an exact method of specifying the amount of stereopsis possessed by any observer. So far as I am aware this has never been done. Some of the difficulties which stand in the way of such an accomplishment will be made clear after you have observe the other figures presented subsequently in this series.

Prepare slide No. 5 as follows: This sli consists of two black circles on a white background. The radius of the left hand circle is 15 mm. and it is drawn from a center 37 mm. to the left of the midline. The right hand circle has a radius of 16 1/2 mm. and its center is 35 mm. to th right of the midline. When examined in the stereoscope, these circles combine to form a single annulus, the enclosed white space of which differs in brightness and in position from the background on which it lies. Now with a pen and some black ink, place a 2 mm. dot about 2 mm. to the left of the circle and about 2 mm. above the mid-horizontal line on which the center of the left hand circle lies. Now carefully re-examine this figure and describe it as if it were an entirely new figure. What effect is produced by the addition of the dot? It will be noted that the circular surface stands out more sharply towards the observer after the do has been added, and that the dot gives location to the homogenous background. Thu a single dot added to the total figure pr duces a radical transformation in the total stereo-experience.

Stereogram No. 6: Draw two circles as before, this time making the left hand circle and also the right hand circle with a radius of 16 mm. Let the center of the left hand circle be 34 mm. to the left of the vertical midline and the center of th right hand circle 35 mm. to the right of the midline. From the same center on the right, draw a second circle with a radius of 19 mm. About 1 mm. to the left of thi second right hand circle and slightly above the horizontal midline, place a 2 mm. black dot. On the same horizontal midlin in the left hand figure, place similar black dots, one just outside the circle to the left, and the other just inside th circle at the right. Place this figure in the stereoscope. If the focus is not appropriate for perfect vision, readjust the focus slightly. Describe carefully what you see. It is worth the effort to make an additional stereogram identical with the above with the exception that here the three black dots are omitted. What does a comparison with the preceding one show?

Stereogram No. 7: Draw very lightly in pencil the horizontal and vertical midlines on a blank card. This stereogram is to be composed of two sectors of circles having unequal radii. Thus it can be seen that we are utilizing here what essentially amount to parts of two completed circles as seen in one of the previous figures. Measure carefully 18 mm. on the horizontal meridian to the left of the vertical midline. Set one point of your compass at this point. Draw a sector of a circle whose chord measures 28 mm. This can be done by setting your compass with a radius of 20 mm.

On the right horizontal line, set a point 31 mm. to the right of the vertical midline. Two mm. above this, place a point. Set your compass for a radius 28 1/2 mm. Draw a sector whose chord is approximately 28 mm. in length.

It is obvious that the two arcs are asymmetrical and cannot be superposed. If the lines are carefully drawn in ink, you will observe that in stereo-vision, you see a curved line which resembles a parabola tangent to the plane of the card at the rear and with the open ends facing toward the observer about 15 degrees eccentric to the right of the line of sight. When the stereoimage is at its best, carefully insert a millimeter scale in the vertical position to measure the chord of this arc and you will find it to be approximately 30 mm. Obviously there has been no vertical foreshortening of the figure.

Stereogram No. 8 along with No. 4 of this series give the two fundamental experiments of stereoscopic vision. No. 8 should be constructed as follows: It consists simply of two vertical lines slightly displaced with respect to each other. The left hand line is 40 mm. long. The right hand line is 42 mm. long. In the left half of the card, place a dot 34 mm. to the left of the midline and toward the bottom another dot 37 mm. to the left of the midline. If these two dots are 40 mm. apart and joined by a solid black line, this completes the left hand figure.

In the right hand figure, place a dot 33 mm. to the right of the midline at the top, and another dot at the bottom 35 mm. to the right of the midline. If these two dots are 42 mm. apart and are joined with a thin black line of the same width as figure on the left, the stereogram is now complete. Examine and carefully describe this figure in the stereoscope. Now re-examine stereogram No. 4 and carefully compare these two stereograms. From the analysis of this comparison, set down every fact possible regarding relative displacement, superposition, disparation, and all other conditions which influence fusion. Stereograms No. 1, 2, 4, and 8 should provide you with first fundamental generalizations applying to stereo-vision. Next month we shall continue and extend the analysis with some more complex figures.

Demonstrations in
Psychological Optics

OPTOMETRIC EXTENSION PROGRAM

STEREOPSIS II.

September - 1941 Vol. 2 No.12

Samuel Renshaw, Ph. D.
Ohio State University

The objective in this final paper is to give you a few instances which may be examined in order to demonstrate some facts about binocular single vision. These facts are not easily reconciled with the alleged law of relative displacement. This principle implies that the control of the third dimension rests solely with the position of objects in the horopter which are projected upon dissimilar retinal points and are seen singly. Such a proposal, it is at once evident, takes no stock of the fact of the strength or weakness of the figure itself, or the strength or weakness of the ground in which it is seen; and it implies that several such matters play no important role in the final perceptual product. The problem usually is solved by asserting that stereopsis is achieved when fusion takes place. This word "fusion" is a form of verbal magic. No one clearly understands what it means.

A further difficulty which points to the fact that the law of relative displacement is not a scientific law at all was pointed out by Ernst Mach about 1865. Mach showed that stereo-vision may be attained where the right and left figures are shown successively. The temporal interval separating the separate exposures can be large enough so that fusion of the second sensory stimulus with the after-discharge of the previous first one is impossible, yet stereopsis is perhaps even more perfect under these conditions than it is with the stereogram viewed in the conventional manner. The greater increased depth effects seen in motion picture photography is ample testimonial to this fact.

A further difficulty with the principle of relative displacement arises out of the known facts regarding retinal rivalry. Washburn has shown that rivalry goes on constantly during stereoscopic vision. Further she has demonstrated experimentally that when rivalry stops there is no stereopsis. If these results are true then all stereoscopic vision results from successive stimulation and alternative suppression in each of the two eyes.

A third interesting light upon the demands of the law of relative displacement arises out of the experiences in our own laboratory with an instrument known as the Kirschmann universal stereoscope. This is a device which enables the experimenter to place the two test objects in a practically limitless number of relative positions in three-dimensional space. For example, the right eye figure can be set at such an eccentric angle with respect to the left that tremendous fore-shortening is introduced into the right eye image. By such means the limits can be measured designating the points at which break-fusion occurs. If we plot the stereo-horopter by such means, we may observe that in some meridians there is an almost unbelievably wide latitude within which stereoscopic vision is not interfered with by image displacement in the slightest degree, whereas in other meridians the range of toleration may be a matter of a degree or two of visual angle.

Finally we must consider the suggestion made originally by von Frey that the whole retinal process in the discrimination of the third dimension serves merely as a trigger to release motor processes which are the true vehicles which carry the meaning of solidity and distance. The simple beginning of this function is to be observed in the phenomenon of visual apparent movement and in the so-called illusions of reversible prospective. This is why an early paper in

this series asked you to make some observations along these lines.

For several years I have observed and been interested in the large possibilities of improvement through training in stereoscopic skill. It is a common experience in our laboratory that students studying visual space develop rapidly the ability to see in the third dimension. The real possibilities here are essentially unexplored at the present time. The architect, the engineer, and the draftsman as well as the professional microscopist all know full well the essential truth of the above assertion relative to the matter of regarding this visual function as a skill.

Let us go back to Slide No. 4 described last month. Let us modify this slide so that to the left we have a pair of parallel lines, to the right we have a single vertical line. The instant we attempt visual superposition by means of prisms or decentered spheres, fusion takes place and the right hand member of the left pair is fore-shortened and appears to lie in a plane nearer the observer. If now we close the top and bottom of the left parallel lines with even a fine hair line that is barely visible and re-examine this figure, fusion is immediately made impossible. Nothing has been changed which would be demanded by the law of relative displacement in this case. However, the minute we transform the two parallel lines into what the observer now describes as a single rectangle, this new figure resists any tendency to transform or distort it. Rivalry will be seen. There is no fusion. Obviously, therefore, a closed figure has a member inertia. It tends to maintain itself. It brooks no compromise in the attempt to make a new three-dimensional form. The only conclusion that one can draw from such observation is that the intrinsic form organization of the figures comprising any stereogram is a highly important factor in determining the degree of binocular single vision and of depth and solidity. And, the perceptual frames of reference (habit relief) are just as important as figure properties, because the stimulus pattern can never be more than a part of the total essential process.

Let us now examine a further simple case. The two stereograms in Figure 1 show first a solid pyramid which extends toward the observer. The second figure is identical with the first except that the apex of the pyramid has been cut off to form a small plane surface. If you draw these figures and examine them in a stereoscope, you will find that the truncated pyramid possesses a distinctly greater degree of tri-dimensionality than does the upper figure. Write out your own analysis of the conditions which produce this differential effect.

Another interesting phenomenon is experienced when we view Figure 2. Note that it consists of a single straight line on the left and an obtuse angle on the right. Logically, perhaps, we should predict that the stereoscopic combination of these two different figures should produce something resembling an elongated capital letter K. If you observe this figure, you will see that nothing of the sort happens. There is a complete suppression of the left hand member. The angle formed by the right hand figure seems to rest with its legs touching the plane of the card and with the apex near to the observer and rotated slightly into a new position. Here we have an instance of stereopsis without fusion. The dominant figure maintains itself with the slight concession of a change in position.

If you examine Figure 3 stereoscopically, you will observe the well-known phenomenon of luster. Here we have a case of superposition of a black and a white object. In the ordinary sense of the term fusion, they should mix or blend to produce a gray. However, the resultant discrimination is that of luster, in which both figures appear as filmy transparencies. This must then be still another kind of fusion and it presents a most difficult problem for those who insist upon a rigid adherence to the teachings of conventional physiological optics for the explanation of stereoscopic effects.

Now make another stereogram similar to Figure 3 except that in this instance the black figure is on the right as before and the left is entirely white, omitting the boundary lines which enclosed the white space to the left in the previous instance. Note before you examine this new figure stereoscopically that all of the same conditions, except one, obtain here as before. If the two halves of this stereogram are superposed visually, there should be the same mixture of white and black which gave luster previously. Try it and observe

carefully what happens.

The upper of the two stereograms in Figure 4 gives a very clear tri-dimensional form which seems upon examination to stand out in front of the white plane of the card with a single point at the rear in contact with this plane. The lower stereogram is a similar solid surrounded by circles of slightly different diameters. Note that the effect of these circles is to differentiate the ground into at least two planes. Note and carefully describe the difference in the stereoscopic appearance of this second stereogram compared to the first. Look at it several times.

These are only a few of many illustrative examples of the general fact that the phenomena of stereoscopic vision are by no means simple. When we extend our observations still further by utilizing the after-image procedure for example, a whole new realm in the investigation of stereopsis is opened to us. It simply is not possible in the limited space here to do more than mention the fact, so brilliantly demonstrated by Professor Kohler at our recent research conference here, that the after-effects of visual stimulation of this sort play an amazing role in all functions involving tri-dimensional vision.

During the past two years, I have sought to interest you in some of the important possibilities of the study of psychological optics. This work now comes to a close. It is my hope that you have received from these papers some stimulation to lead you to an expanded concept of the lines along which subsequent developments must proceed if optometrists are to achieve a professional status other than that of mere technologists. For to learn to control functions we must first learn to describe them clearly and fully.

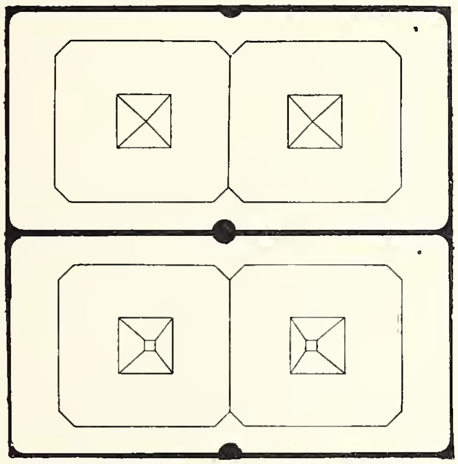

Figure No. 1

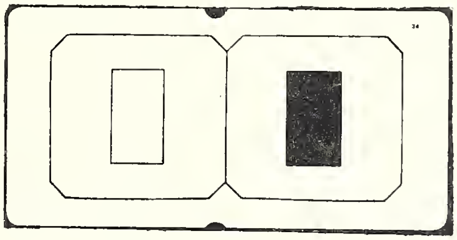

Figure No. 3

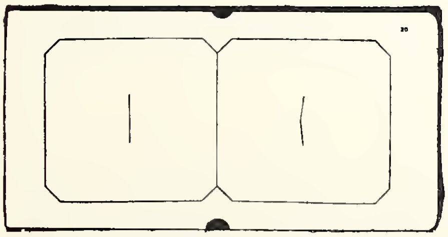

Figure No. 2

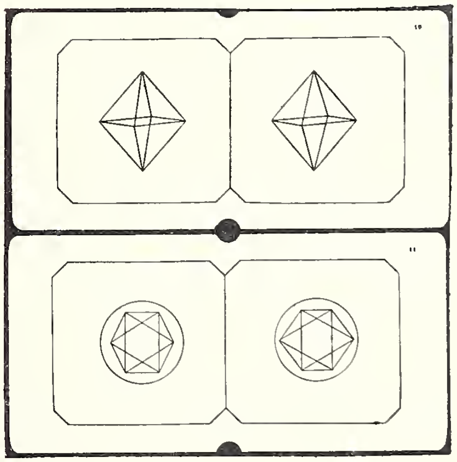

Figure No. 4

Psychological Optics

—BY—

SAMUEL RENSHAW, Ph. D.
Ohio State University

OPTOMETRIC EXTENSION PROGRAM

October - 1941

THE REDUCED EYE

Vol. 3 No. 1

The plan for this third series of papers involves first a review of a few fundamentals. Later we shall have occasion to refer back to this first paper which deals with the concept of the hypothetical average eye.

It may seem a bit elementary to review these considerations at this time but considered as a refresher I believe the undertaking can be justified. It is probably not altogether impossible that a careful study of these pages may give you some slight additional clear understanding of some foundational facts upon which turn important subsequent arguments.

Just as soon as one begins to study problems of acuity, size, and distance, stereoscopic vision, or any visual problem involving precision measurements, one is forced back to the set of constants which describe properties of the emmetropic or "normal" eye. It should be clearly recognized at the outset that the norm is a fiction, derived by a process of calculation, which has no real existence. Anything or system is normal only with respect to the aggregrate of field conditions in which it operates. Consequently, we must conceive the norm always to be a range of dynamic interplay rather than as a static construct. If we search for physical or biological constants we shall find them exceedingly rare. We are all familiar with the frequently encountered literary references to the fact that there is nothing constant except change.

Even brief consideration must show that the constants which describe the schematic or reduced eye are but a convenient and arbitrary starting point for subsequent investigations. If we wished to establish the constants of measurement for an ideal schematic eye, such procedure would necessitate that we enucleate the eyes of a true random sample of the population of the earth; that a large staff of highly trained experts using identical methods should take measurements upon these excised organs and that at the conclusion of this great labor two sets of statistical values could then be stated. The first of these would be the mean or average values derived from the readings of the instruments for precision measurement. The second would be the necessary measures of variance which give significance to the first. Without these latter values we should find that the former ones, namely, the means or averages would not be of much use to us.

If we search the literature for these defining constants, we find values derived largely from calculation rather than measurement. And these values are in terms of the closest rational approximation to what the true average might be expected to be if someone performed the ideal but prohibitive labor indicated above. Nowhere do I find the necessary variances given and nowhere do I find a satisfactory account of the extent to which sampling errors can and do enter into the computations.

These things we must constantly bear in mind when we must make calculations based upon such constants for the interpretation for experimental and clinical findings.

For the sake of illustration, let us look at the characteristics of the phakic eye described first by Listing in 1853, then later by Donders, and more recently by Gullstrand and Tscherning. Let us examine two sets of values given by each of the above authors of a reduced eye.

	Listing	Donders	Gullstrand	Tscherning
Anterior Focal Length - mm.	-15.1774	-15.0	-17.054	-17.13
Posterior Focal Length - mm.	20.4742	20.0	22.785	22.89

Note that none of these agree perfectly although the differences are in most instances small enough so that for some purposes they may not be significant. For other purposes they most assuredly are. For example, the disagreement between Donders and Tscherning as to the anterior focal length amounts to 2.13 mm. It would certainly make a tremendous difference therefore which of these schematic eyes we were to take as the basis for calculation in determining any one of several interpretative values.

The reduced eye of Gullstrand seems to be more frequently used than any other. The reason for this is probably a pragmatic one, namely, that these constants seem to work within a more satisfactory range of variance. Figure 1 following is a rough sketch of the eye giving Gullstrand's constants.

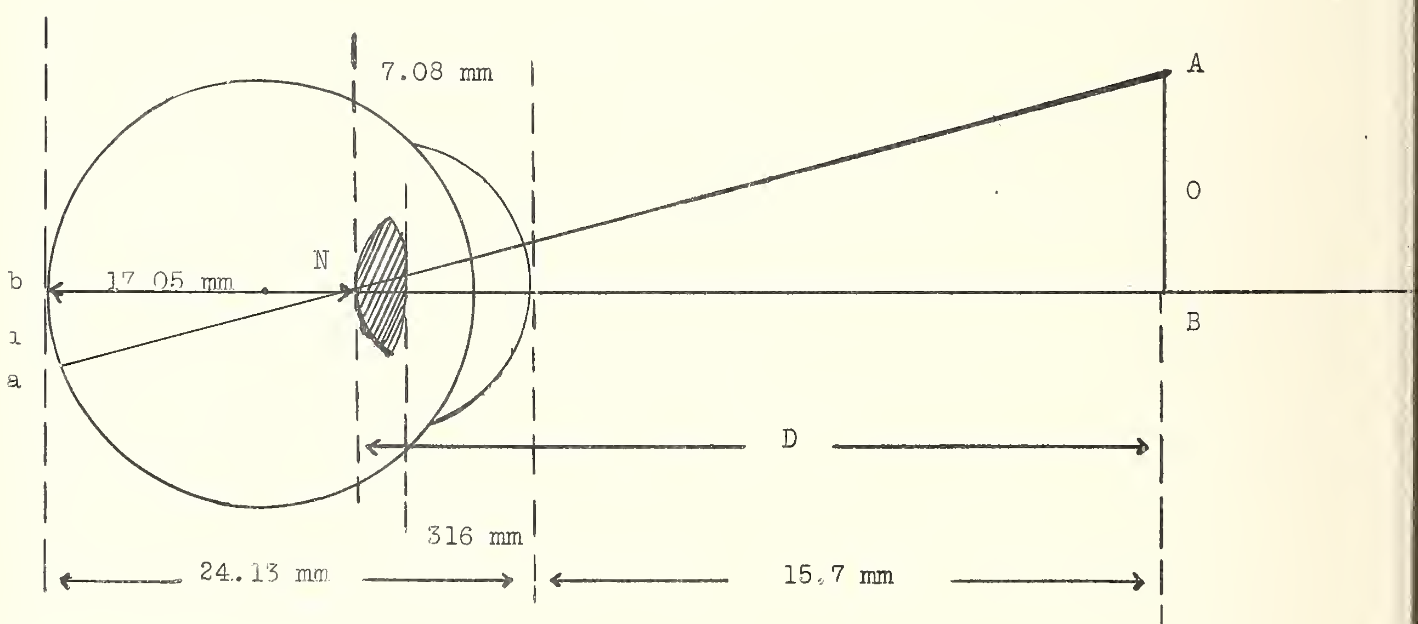

Fig. 1

This eye is regarded as an ideal sphere with a radius of curvature which is 5.73 mm. Its principle point lies 1.35 mm. behind the anterior surface of the cornea, that is in the anterior chamber. Its optical center or nodal point is 7.08 mm. behind the anterior corneal surface, that is, in the posterior part of the lens. The anterior focal distance is 17.054 mm. (or 15.7 mm in front of the cornea), and its posterior focal distance is 22.78 mm. (or 24.1 mm. behind the anterior surface of the cornea) which point in a normal eye lies upon the retina. The refractive power of this eye is +58.64 diopters.*

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* For a detailed list of the constants of Gullstrand's schematic eye see Southall, J.P.C., Introduction to Physiological Optics, Oxford University Press, London, 1937, pp. 54-62.

From these constants we may derive the method of determining the size of the retinal image; that is, the area of the retina excited by the stimulus of known size at a known distance from the nodal point of the eye.

Let O equal one dimension of the stimulus object. Let i be the area of the retina stimulated (the 'size of the image'). Then in Figure 1, O=AB and i=ab. D=BN. Note that D equals the distance of the object to the front of the cornea plus 7.08 mm., the distance from the anterior surface of the cornea to the nodal point.

Since the angle A N B equals the angle oa N b we may write

$$\frac{ab}{AB} = \frac{bN}{BN}$$

from this we may write

$$ab = AB \times \frac{bN}{BN}$$

bN = 17.054 mm. and since ab = i and AB = O we may write

$$i = 17.05 \times \frac{O}{D}$$

One dimension of the retinal image may thus be determined if we multiply the ratio of one dimension of the object in mm. to its distance from the nodal point in mm. by the constant 17.05.

It may be more convenient to express the image size in terms of the tangent of the angle A N B, which is $\frac{AB}{BN}$ and this is $\frac{O}{D}$, thus i = 17.05 x (tan A N B).

Suppose we wish to determine the size of the retinal image of a white square one dimension of which is 30 cm. at a distance of 3 meters from the eye; then

O = 300 mm.
D = 3000 + 7.08 = 3007.08 mm.

$$i = 17.05 \times \frac{300}{3007.08}$$
$$= 17.05 \times 0.09976 = 1.7009 \text{ mm.}$$

which is one dimension of the square image patch. The image therefore covers an area of 2.89306 square millimeters. It is interesting and illustrative to calculate the image sizes of common objects seen at various distances from the eye. Work out the answer to the following problem: The standard Snellen letter E which subtends a visual angle of five minutes at twenty feet or 6.1 meters measures 9 mm. x 9 mm. What is the area of the retina stimulated by this letter at the distance given? What is the size of the "image" at 1 meter, 3 meters, 12 meters, 24 meters, 48 meters? How does "image" size vary, in general, with distance?

Sometimes it becomes interesting and important to know the minimum visual angle for any given test object. This is the tangent of the angle a N b, which is equal to $\frac{ab}{bN}$ or $\frac{0.002}{17.054}$ = the tan of 24" 14. in the above equation the value 0.002 is a diameter just greater than one macular cone.

Suppose we regard the eye as a miniature camera. Let us assume that it has a 15 mm. objective. Let us assume further that the pupil is an aperature of 3 mm. The "speed" of such a lens is therefore f=1.5. It is interesting and instructive to calculate the hyperfocal distances of such an f5 lens. It is also tremendously interesting when you have completed these calculations to consider the results you have secured in terms of the known functional relations of accommodation and convergence in the human eye. In 1930 Hartridge showed the influence of pupil diameter upon the depth of focus of the eye when it was focused on infinity and also upon an object at 25 cm. The following table shows the influence of pupil size upon depth of focus at these two distances.

Pupil Diameter	Depth at Infinity	Depth at 25 cm.
1 mm.	to 8 m.	3.2 cm.
2 mm.	to 16 m.	1.6 cm.
3 mm.	to 24 m.	1.1 cm.
4 mm.	to 32 m.	0.8 cm.

The careful working over of such materials as the above will give a sound basis for thinking with regard to many clinical and experimental problems in vision. If it is felt that the materials in this paper are sketchy and abbreviated everyone has ready access to treatises and text books which give much more detailed expositions of these problems. It is doubtful whether anyone has too firm a grasp or too clear an understanding of the fundamental issues involved in dealing with the constants of the reduced eye.

It is easy to show by calculation that as we vary the distance of a test object, the area of the stimulated patch on the retina varies inversely until a limit is reached at the vanishing point. It is also easy to show that what any eye sees, so far as the size-distance relationship is concerned, cannot be deduced logically from these values. This discrepancy between logic, mathmatical analysis, and geometrical optics, and the thing immediately experienced by the observer is the basis of the two opposing schools of thought among all workers with visual problems.

It is particularly opportune to give careful consideration to this question at this time for it is of great importance in view of its bearing upon the year's program whi[illegible] is to be devoted to the general problems centering around near-point refraction.

Psychological Optics

—BY—

SAMUEL RENSHAW, Ph. D.
Ohio State University

Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

THE REDUCED EYE AND RESOLVING POWER

November - 1941

Vol.3 No.2

Last month we reviewed some of the properties of the schematic eye which is to be taken as the emmetropic pattern. In order to secure clear, comfortable and effective vision some approximation to this state is sought. We think of the eye examination, among other things, as a determination of the ability to properly posture the globes, and a measurement of the power of monocular and binocular resolution.

Resolving power of the eye depends upon three factors: First, the image forming function of the lens system; second, the grain or density of the rod-cone population of the retinal surface; and, third, the psychological factor which includes such things as the degree of training of the observer, the structural organization of the visual pattern which serves as the target, its illumination and contrast characteristics, etc.

It is well known that whenever a lens forms an image of a point there will be a certain amount of diffraction at the boundary so that the image is not a point but a disc or circle surrounded by rings. This is known as the Airy disc or blur circle. When the point is seen at a distance the radius of the first dark ring is given by the formula:

$$\frac{1.22\ F\ \lambda}{d}$$

where F is the focal length of the lens and d is its diameter. λ is the wave length of the incident light. Astronomers have shown that two stars can just be resolved when the center of the disc of one falls on the first dark ring of the other. The angle between them then is $1.22 \frac{\lambda}{d}$ in radian measure. If the pupil varies from about eight mm. in dark adaptation to two mm. in bright light, and we calculate substituting these values of d in the above equation and assume that the value of λ or the wave length of light is about 550 mu mu which is about the yellow at maximum visibility of the daylight eye, we obtain angles equal to 0.29' and 1.15' of arc. The resolving power is maximal when the diameter of the pupil is about two mm. This is because when the pupil is larger chromatic and other aberrations come into play and we do not secure the increased definition which the above figures might lead us to expect. Considered as an optical instrument the eye should separate two point sources whose centers are 1.15' apart.

Notice also that resolving power should vary inversely as the wave length of the light.* All of the above assumes that the grain of the retina is fine enough not to influence definition. The diameter of the foveal cones are usually taken as of the order of 0.5". In the fovea these are hexagonal shaped. If the blur circle is large enough to fall on three adjacent rows of foveal cones, the separation should be approximately 1' of arc and it therefore seems that the retinal grain is fine enough to utilize fully the resolving power of the lens system. This balance between lens definition and retinal microstructure seems to have been attained through long periods of biological evolution.

Based on Gullstrand's schematic eye the smallest image of a test object on the retina is given by the formula:

$$i = 0.291\frac{\epsilon}{F}$$

where the value of i may be stated in millimeters if ϵ, or the visual angle subtended, is given in minutes and F = 58.64 diopters. Thus for a test object subtending 1' the diameter of the smallest retinal image is found to be almost exactly 0.005 mm. It should be remembered that this is an idealized computation and does not take stock of aberrations resulting from light transmitted through a small circular opening and through the lens and media. However, for a three mm. pupil and

light at 570 mu mu the value ϵ is about 0.8' which is close to the resolving power of the so-called normal eye. This gives for the minimal size of the retinal image a value of approximately 0.004 mm. which corresponds fairly well to microscopic measurements of the foveal cone diameters made by Kolliker, Koenig and others.

The tangent of 1' equals $\frac{1}{3438}$. This means that it is impossible for the eye to distinguish details of form in an object whose distance is 3438 times as great as its largest linear dimension. A silver quarter dollar is approximately 24 mm. in diameter. If we multiply 24 mm. by 3438 we get 82512 mm. Theoretically if we view the quarter at a distance of 82 1/2 meters it will subtend an angle of 1' of arc and should appear therefore as a mere point. Last month we suggested that you compute the retinal area of the standard Snellen E at 6.1 meters. This area was calculated to be 0.000625 square millimeters. If we assume a blur circle for the average eye at .01 inch or .254 mm. then one dimension of the Snellen E at 6.1 meters is about one-tenth of the diameter of the blur circle.

Since all of us are interested in acuity let me suggest an interesting and instructive experiment. Take a standard AMA Snellen chart. Mount it on a ring-stand so that its center is at eye level. Go out into a large flat field. Take along a camp chair and a meter stick. Measure off carefully by setting a series of small wooden pegs in the turf at distances from one to one hundred meters from the eye position. Determine your own acuity at 6, 12, 24, 48 and 96 meters. Carefully record this data. Then return to your home or office and carefully measure one dimension of each of these test letters. Now calculate the retinal image sizes for your thresholds of visibility. If the flat field is not available use whatever type of acuity device you have in your office. You will find the results you get will amply justify the labor and I can guarantee that it will set you to thinking critically about the problem of acuity and its measurements.

During the month of August, 1941, I made a series of observations such as those described above. These were made between nine and eleven A. M. on each of several days. A standard direct reading AMA Snelle test chart, published by Bausch and Lomb, was used. A Weston master light meter gave a reading on the test chart of 225.

Acuity ratings were taken on Dr. McFadden and myself. McFadden's vision had been checked by Dr. W. A. Sherrard using the complete analytical examination with the result that no lens correction was indicate My own vision was also checked by Dr. Sherrard with the following result.

+.75 -1.00 x 105
+.75 -1.00 x 80
add
+1.50
+1.50

All my judgements were made wearing these lenses.

Let us look first at McFadden's results. When the test chart was 48 meters from the observer's eyes, he read line 11 (29.7 meters) correctly. Line 10 (26.5 meters) was reported as N T R C with the comment that he was not sure. These letters are H T S C. That is, he got half of the letters in this line correct. In line 9 (23.6 meters) he read U V Y P. Here the only mistake is Y for V. All letters above line 9 were reported as "beyond reading." At 48 meters therefore this subject reads correctly three-fourths of the letters whic he should just barely have been able to read at 23.6 meters. Judged by the AMA standard this is a little more than 100% more resolving power than a normal pair of eyes should exhibit.

At 24 meters lines 7, 6, and 5 were read correctly. Line 5 is marked 13.7 meters. The letters are C V O F E H S. Line 4 was reported as badly blurred. Consequently we must conclude that this observer was seeing perfectly at 24 meters what he barel should have been able to distinguish at 13. meters. If distance is the paradigm of siz then for this observer under these conditions his acuity should be designated as $\frac{24}{13.7}$.

Next the chart was placed at 12 meters. No difficulty whatever was experienced in reading line No.1:

L T V U P R H Z C F D N G

This is the standard at 6.1 meters and the ease with which the letters were called off points conclusively to the fact that had there been another line smaller than No.1, he undoubtedly would have gone considerably beyond this limit.

In my own case at 48 meters I was able to read lines 17 to 11 inclusive without any difficulty. Line 11 is marked 29.7 meters. Line 10 (26.5 meters) I read as N T E C with the commentary "Not sure, except T and C or G. All above are blurred." That is, I was able to read correctly 50% of the letters at 48 meters which I should barely have been able to distinguish at 26.5 meters. The target was then placed at 24 meters. Line 6 (15.9 meters) was read off immediately without error. Line 5 (13.7 meters) was also read off without hesitation and without error. Line 4 was badly blurred and not letters could be distinguished. This means that I was able to read at 24 meters letters which I should only have been able to read at 13.7 meters.

The test chart was now brought to 12 meters. I read all letters in line 1 (6 meters) without any difficulty.

These observations call for some care in interpretation. First we must consider that the charts were seen in bright sunlight on a clear day in an open field where the intensity of illumination was many times that found in the average office. However, it is doubtful if this difference could account for such discrepancies as were observed in these findings over the AMA standards for acuity. If the readings had been taken in a poorly illuminated room the increased sensitivity due to partial dark adaptation may be enough to partly or wholly offset the advantage of viewing the chart in bright daylight. The next question which arises then relates to the manner of standardizing the chart itself. If the letter sizes were determined by calculation the makers fail to take stock of the sources of error indicated in the earlier portions of this paper. If the standardization was accomplished by a statistical sampling of the adult population then the change in the conditions of observation which we employed invalidated the results. I should prefer that you place your own interpretation upon these findings. One thing, however, is certain that so long as the resolving power of the eye is susceptible to great improvement through training all such standardizing devices for the specification of acuity must be regarded with questioning reservations.

This brings up the third set of factors which influence resolving power. These are the psychological factors. Last year you received a summary of a series of experiments completed in this laboratory on the influence of training and some other factors on the resolving power of the eye. Soon you will receive some further papers which will throw additional light on these problems. The question of the size-distance relation is far from settled. Some advance has been made in recent months along these lines and I hope to report later some of our findings. The following simple observation will help to introduce the problem to your thinking. Prepare a stereogram card 3 1/2" x 7". Take two new quarter dollars and mount these with rubber cement so that their centers are 70 mm. apart. Be careful to center them properly on the card. Place the card in a stereoscope and adjust the focus so as to secure good fusion. If the diameter of one of the coins is 24 mm. its total area will be 452.39 square mm. With a draftsman's compass take a large piece of white cardboard and draw a series of circles the smallest 20 mm. in diameter and the largest 32 mm. in diameter. Look at the stereo image of the quarters and then look quickly at the series of drawn circles. Select the circle which is judged phenomenally equal to the fused image seen in the stereoscope.

When I do this I match the actual stereo image of the quarter with a circle whose diameter is 29 mm. Such a circle is 660.52 square mm. in area. The difference between the true area of the target, namely 452.39 square mm. and its apparent area 660.52 square mm. is 208.13 square mm. The viewing lenses in the stereoscope I used are decentered +5 spheres. Thus to me the quarters appear exactly 46% larger than they really are. At once several questions arise. Is this large increase in apparent size a direct measure of the magnifying power of the lens system? If we shorten the focal length of the lens system what effect will this have upon the phenomenal match of size? If another person with

about equally good vision makes an individual match how will his judgement of apparent size compare to my own? If there are large discrepancies from individual to individual in apparent size how do these check with other properties of our respective visions? In forthcoming papers we shall give detailed consideration to questions such as these and shall present some experimental evidence which we believe throws additional light on the visibility of objects seen both in stereographic form and in the simple conditions of everyday seeing.

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* The dependence of acuity upon intensity of illumination has been extensively investigated, first by Uhthoff in 1886 and later by Koenig in 1897. They found that the relationship between visual acuity and the logarithm of the illumination is sigmoid in form. Neither of these earlier investigations took stock of pupil size or the distance of the test object from the observer or the brightness and extent of the field surrounding the test object. Since that time Hecht, Lythgoe and Tansley, and particularly Shlaer have made very careful determinations of all these factors. The results of Shlaer are particularly significant. His results were published in the Journal of General Physiology, 1937, 21, 165-188.

Psychological Optics
—BY—
SAMUEL RENSHAW, Ph. D.
Ohio State University
 Duncan, Okla.
OPTOMETRIC EXTENSION PROGRAM

EMMERT'S LAW AND THE SIZE-DISTANCE RELATION

December - 1941 Vol.3 No.3

This month we shall continue and extend the considerations treated in the two preceding papers. The importance of the size-distance relationship for the refractionist needs but one fact for its justification. When black parallel bars subtending 1 of visual angle are set in a white ground and viewed through artificial pupils under constant illumination at a distance d, the observed condition known as the "constant separable" may be stated. When this point is determined, both trained and untrained observers report that field forces in the undifferentiated ground seem to exert a constant centripetal pressure which forces the bars to blur and fuse. Second, a universal report is that the apparent position of the target (the bars) is constantly shifting. They drift about and this makes resolution additonally difficult.

If we introduce some structural organization in the undifferentiated ground such as line drawings of simple common objects instantly two important things happen. These things happen regardless of the size or form of the figures introduced into the field. First, the position of the bars becomes stabilized. Second, the distance d at which constant separability is attained is increased. The magnitude of this increase is found to be in the neighborhood of 20%.

The conclusion we must draw from these observations is that phenomenal size is an important determinant of resolving power. Any consideration of visual acuity and its measurement which fails to take stock of this important principle is bound to be wrong.

In some of my lectures before various optometric groups I have shown the photograph of the single track causeway on the Southern Railroad crossing Lake Pontchartrain near New Orleans. The rails stretch away converging into the distance and meet the horizon. I pasted upon the enlarged photograph of this scene a figure 3 in 36 point type at the point where the rails meet the horizon. I pasted an identical three in the center of the rails in the near foreground. When I first showed this picture to a class of students and asked them to compare the apparent sizes of the two threes, the response was uniform and invariable, the figure in the distant position seemed distinctly larger when compared with the figure, of identical size, in the immediate foreground.

Here we have a further demonstration of Martius's famous experiment in 1889 in which he observed that while retinal image size may remain constant, phenomenal size may vary considerably.

When we modify the surrounds in which a test object is seen and thereby change its phenomenal size, do we also alter the resolving power of the eyes comparably for this same test object? This question can be answered in the affirmative because when we placed these same figures in the target holder of the acuity meter developed in this laboratory, and measured the maximal distance at which each of the 36 point threes could be clearly and sharply resolved, the distance was greater by approximately 20% in favor of the far or horizon position.

Emmert's law was first stated in 1881. It maintains simply that the projection either upon the retina of a light pattern or of an after image upon a projection surface at a specified distance in front of the nodal point of the eye will exhibit the state in which the area of the image or the projection will vary directly with the distance. Turn back to the diagram on page 2 of the first paper in this series. On the horizontal line representing the line of sight about an inch to the right of the point marked B set another point

B'. From this point erect a perpendicular. Prolong the angular line aA until it intersects this perpendicular. Mark the point of intersection A . At the middle of the perpendicular line write O'. Note that D represents the distance from N to B. Draw another line D from N to B'. Emmert's law merely states that the retinal projection of both O and O will be identical. If the law were true it should be impossible to distinguish which of two objects was nearer the eye if the larger of the two objects were placed at such a distance that it subtended the same visual angle as the smaller nearer object.

This problem has had a long and interesting history which we cannot discuss here except to say that when the principle was tested experimentally, it was found that the duration of the exposure was a decisive factor. Very brief exposures give one sort or result. Longer or continuous exposures give a different sort of result. The problem, therefore, involves something more than that given in the formulations of Emmert, Aubert, Forster and more recently by Ellis Freeman. It has long been recognized that relatively large changes in visual angle can be made with only slight changes or no changes at all in apparent size. In the illustration cited above we noted a case in which there was even a reversal of the logically expected change in size. The term size-constancy has been used to designate the commonly recognized phenomenon that near objects are seen too small and distant objects too large to conform to the postulation of Emmert s Law.

The question immediately arises, of course, how do these observed facts fit in with the refractionist s philosophy concerning myopia, hypermetropia, aniseikonia and similar problems? It is quite clear I believe that no one will dispute the fact that the ultimate objective of lens application is to provide the best possible approximation to normal seeing. To do this everyone knows who has ever prescribed a lens that under certain circumstances he has to cut + , and take other liberties with the readings of his prescission measuring instruments because he knows very well that his patient cannot and will not wear his lenses if the calculated lens power is prescribed.

Before me is a list of about twenty investigations of the size-constancy phenomenon The list of investigators who have studied this problem is an impressive one: Martius Hillebrand, Poppelreuter, Schubotz, Blumenfeld, Brunswik, Holladay, Thouless, Werner, Cutler, Weber, Locke, Frank, Hermans, Helson, Berryl, Boring, Katona--- to mention only a few. For the past four years I have been making experiments on this problem both in the laboratory with various kinds of optical instruments and out in the field under ordinary conditions of seeing.

Let us consider one problem, simple yet of very great importance, which arises in the study of the size-distance relation. This problem can be illustrated quite simply but first let us consider a contribution from Professor David Katz who introduced the concept of <u>reduction</u> into the psychology of perception. The net percept of any object is a product or function of a number of determinants. Some of these are primary in the sense that they are indispensable to the perception although they may not play the principal role in determining the exact size, shape, form, position, or magnitude of the percept. Other determinants may be regarded as secondary and their functions may operate either to enhance or diminish the final outcome in perception. Katz believed that if suitable means could be developed for the control of these secondary determinants the perception should be reduced in the direction of the primary determinant. His studies were largely in the field of apparent brightness and hue so that by means of what he called a reduction screen, which excluded the influence of surrounds, he was enabled to study brightness under conditions reduced to a state determined almost entirely by the single factor of the actual retinal illumination.

Thouless independently studying the same problem proposed the principle known as "phenomenal regression to the real object. If we move an object farther away and thereby reduce its visual angle the object exhibits an inertia like function in that it does not get smaller proportional to the increase in distance. It is as if objects like to have themselves seen at a size which is for them an optimum and they decide for themselves "I will be jigged

if I will permit any liberties to be taken which would tend to exhibit me to an observer falsely."

It is not difficult to devise a means of measuring accurately the phenomenal size of objects. Here the psycho-physical method of equivalents may be utilized. Suppose I have fixed to a large sheet of cardboard a series of common wire nails differing from each other by one mm. and ranging in size from five mm. to 100 mm. in height. Suppose I hold up a sample nail twenty inches in front of your eyes and ask you now to look at the card and select a nail which is an exact duplicate of the one you are seeing. It is clear that with almost no training at all this matching process can be done with great consistency and accuracy. Suppose now I take the card into another room. I show you another nail whose size is unknown. This time we place -1.0 spheres before each of your eyes. We give you a good look through these lenses, remove the nail from your sight and the minus lenses from your eyes and two minutes later ask you to go into the next room and now from memory select a nail which is an exact match for the one you just saw in this room. If we also make the comparison without the use of the lenses it becomes possible for us to determine by such a method the difference between the size-match with and without the lenses.

There are, of course, many variations of method which may be and have been introduced, but the question raised previously which is of great interest and importance is simply the question: How big is big? How large should any object O, look when it is viewed at the distance s from the eye? If it is true that objects seen at the near point are seen smaller than optical calculations demand then we should obviously introduce a correction. But how much should this correction be? If objects seen at a distance are seen too large then how much should we reduce them in order that we may perceive them truly? The real problem here becomes simply the question: What shall we use as a base or standard of comparison? Should we say that an object at six meters is seen with both accommodation and convergence constant and that, therefore, this apparent size shall be taken as the standard of reference for all other size-distance relations? If so, when we bring the object to three meters or half the distance then its total projection area will be four times the previous value and should we see it, therefore, four times as large? Should we take the so-called near point as the basis for our determination of phenomenal changes in size? What is the near point? The far point?

Everyone familiar with this literature knows for example that in stereoscopic vision the whole concept of corresponding points rests upon extremely shaky and unverified ground. Dodge and others have produced results which deny even the validity of the concept of a single fixation point. Yet notwithstanding such considerations procedures which you utilize every day are based upon postulations such as these. Something ultimately must be done about it. That something has got to be a large amount of careful and painstaking research.

There is another powerful determinant of all visual perceptual processes. This is the factor of training. Every living thing exhibits functions which are in part determined by its internal structural organization, and also these functions can only show themselves to best advantage in what Holt has called "the constant and correct environment." No one knows how much of structure is function and how much of function is structure. Only a brave man or a fool would presume to say. Everyone who through the procedures known as orthoptics tries to reconstruct the visual perceptual world of a patient knows full well that if he is fortunate enough to utilize proper procedures he may produce a satisfactory and perhaps a permanent result. He also knows that he must proceed with great caution because he travels a country in which there are few if any road maps and only a few helpful signs. Here is a frontier. Here there will be rich developments in the years to come.

Psychological Optics
—BY—
SAMUEL RENSHAW, Ph. D.
Ohio State University

 Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

INTRODUCTION TO LEARNING

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As we begin a new year it is fitting and proper that we also begin the consideration of the topic of the papers which will constitute the remainder of this series: Learning. The problems which group themselves about this topic lie at the very heart of psychology. They concern directly every living thing. There can be, therefore, no more important undertaking than to sketch some of the contributions, both theoretical and experimental, to this field.

Let us begin by a brief review of the history of learning as a psychological category. From the time of Aristotle until about the opening of the present century learning presented no particular problem. If an animal or a human being put on a new or varied response to a stimulus the explanation was simply that an associative bonding or linkage had been formed so that subsequent appearance of the stimulus now came to elicit the new movement or idea. The classification of the ways in which this process of the linkage of stimulus and response operated was logically subsumed under four "laws": Similarity, contrast, succession and simultaneity. By the end of the first decade of the century Titchener showed that all four of these principles could be reduced to two or even to one. Similarity and contrast are essentially one and the same process. We can only contrast light and dark by reference to a single continuum of brightness, for example, by comparison on some common or similar basis. Likewise succession and simultaneity merely indicate whether two events occurred side by side or end to end in time. In either case it is a matter of contiguity in time.

So similarity and temporal contiguity seemed to be the basic principles of logical association. But a further analysis showed that to say that A was similar to B presumed that the two had at sometime been experienced in temporal contiguity. Thus similarity became a special case of contiguity in time. To be learned two things merely had to be experienced together in time!

This was all simple logic. No scientific experiments gave results which led to the "law" of association. On the contrary we read that "the reign of associationism was over as soon as ever psychology became scientific."

Here was a simple, easy solution to a legion of different problems. "It explains the appearance of every single idea that has ever occurred to anybody; if offers to take us to the very heart of psychology without need of training or preparation; it flatters us into the belief that we have all our lives been talking and thinking psychology without knowing it; it covers up the gap which separates common sense from science. Small wonder that Hume compared the law of association in psychology with the law of gravitation in physics!"

Small wonder, too, that such a doctrine should gain a firm foothold in the thinking of uncritical persons and remain firmly entrenched even in the face of experimental evidence that under the very conditions specified by the "law" as favoring its maximal operation--it does not hold.

In the last two decades of the previous century biology had moved forward in great strides. The neurone was discovered in the early nineties. Zoologists were active in studies on the problems of primary irritability, of tropism and taxis, of instinct and of those forms of animal behavior transformed through experience. Hobhouse, Holmes, Spalding, Lubbock, Von Uexkull, Loeb, Jennings, Cope, and Lloyd-Morgan were active--and Pavlov read the paper on his observations on 'psychic

secretion of the digestive juices in Madrid in 1902, the beginning of the conditional reflex studies.

Small had adapted the plan of the Hampton-Court maze to the study of learning to secure food with the white rat (99, 00) and Thorndike, then at Harvard, had made and published on his observations on the manner in which cats learned to escape from a latch box to secure food (1898,et seq.). Bourdon, in France, had made some crude experiments on the acquisition of skill, and in 97- 99 Bryan and Harter made one of the first real studies of learning, on the sending and receiving of the telegraphic Morse Code. Biologists were raising questions as to whether protozoa could profit by experience or form new habits: whether instincts were mere chains of concatenated reflexes, and many and acrid were the arguments as to the possibility of the inheritance of acquisitions and the teleological implications of purposive behavior.

As we review the history of the problems classed as "learning" it is clear that systematic and scientific work and attempts to define issues and formulate defensible theories began about forty years ago. The great bulk of the principal literature has been produced in the last 25 years. Our bibliography consists of references to articles, monographs and books and now contains about 4500 titles -- and this is by no means a complete bibliography. How new, then, is the problem of learning. Have we only recently become aware of its significance and worth?

In beginning the study of learning and the many problems associated with it, it is quite important to give critical scrutiny to basic underlying concepts. If we wish to avoid sinking into the morass of confusion we must clearly define these concepts. If the term learning, like any other term, is to be useful to us as a scientific concept it must be capable of clear and unambiguous definition. The first questions, therefore, which raise themselves for our consideration are questions like these: What is learning? What is learned? How does a learned movement differ from one which is unlearned? How far down in the scale of living things does learning take place? Can single celled animals, such as amoeba proteus and paramecium learn?

From one point of view learning is coextensive with life itself. It is as true to say that an organism learns its form and structure as it is to say that form and structure determine what and how much and how rapidly an animal learns. In a single-celled animal such as the amoeba the "head" of the animal is that portion of the animal where the metabolic rate is highest, following stronger stimulation of its plasma membrane in that region than in any other. The presence of a region of high potential or high activity means that some other region usually opposite becomes a region of low potential, and this is but another way of saying that a <u>gradient</u> has been established pursuant to stimulation and the consequent response of the organism. An extensive biological literature since about 1920 has been produced dealing with the concept of gradients, the means of their establishment and the role they play in determining the form and functions of living organisms. From all the many studies it seems clear that we must regard learning as of equal importance with those factors subsumed under the term heredity. Life itself is a continuous dynamic interplay between the organism and its surrounds. In fact it is difficult or impossible to establish a line of demarcation which sharply separates that which is organism from that which is environment. Certainly it is no longer possible to regard an individual organism merely as that which is encased within its limiting membrane or skin.

If we pursue such a point of view then we must greatly expand our conception of the meaning of the term learning. "Learning" thus becomes a symbol representing the set of facts which describe the sum total of all organic and functional changes, some transitory and some permanent, which occur throughout the life of the organism. Learning becomes a class name for the types of things which we call growth, development, differentiation, dedifferentiation and the like. At once, we are impressed with the universality of this principle.

If we consider human beings and their daily behavior and list all the things persons do which have been learned we find it diffi-

cult to point to a single act or movement which has not been established or transformed through learning. We learn to walk and talk. We learn to feed ourselves at specific intervals. We form habits of basic physiological character which keep us alive as well as the polite arts of speech, writing, music and professional endeavors. Try to conceive what you would be like if by some sudden magic you were divested of every learned function.

When we consider this miraculous thing which enables us to remember and forget, and to exhibit the most amazing adaptability to changing circumstances shown by any living creature, then learning must be looked upon as an undertaking second to no other in importance. Likewise, it must be clear that the term learning, if it is to embrace so vast a domain, can hardly become a designation scientifically useful to us. This is because it is a class name for a wide variety of different types of adventitious changes in the form and functions of living organisms.

Let us go one step farther. Suppose that I place a coil of wire about a length of soft iron. If I send a strong direct current through the wire the molecules comprising the iron bar become polarized or magnetized. Is this a mere rearrangement of the particles? One thing is certain, nothing one can ever do is capable of restoring the soft piece of iron to its original status. By hammering it we can partially but not completely demagnitize it, but there is always a residual after effect, called hysteresis. It is likely that all substances, organic and inorganic, exhibit a similar property. If a beam of X-rays are shot through a piece of plate glass on which a small lead plate protects the glass in one spot from the influence of the streaming particles, a permanent after effect remains even in systems such as colloidal emulsions. It is quite likely that any change wrought in an organism by allonomous stimulation leaves that substance in a state of heightened or reduced sensitivity. It is, therefore, quite proper to raise the question: Do the simplest living things, even microorganisms learn in the broad sense outlined above? And can we restrict the term learning to organic or living matter? Or shall we extend the concept to include any adventitious change in the form and function of any substance?

There is probably excellent scientific justification for the view that the only difference between the learning of a stone and that of a protoplasmic cell lies in the amount, rate, and kind of transformations that can be wrought in its structure-function organization.

To learn is an intransitive verb. It does not take an object in the grammatical sense. When I learn a poem or a skilled movement, the thing I am describing is the fact that some aspect of my behavior with respect to the stimulus object has been changed. This being the case, we should look to the concept of energy, its collection, storage, and transformation as the basis of the whole conception of learning, this for the reason that the principal earmark of any learned act is that it is consummated in less time and with less expenditure of energy than was possible prior to learning.

When the blink reflex is elicited by a puff of cool air upon the cornea immediately after a small buzzer has been sounded about a second and a half previous to the puff, and when this sequence is repeated about 20 to 30 times, finally the sound of the buzzer alone will elicit the blink movement. The blink response is said to have been conditioned to the sound of the buzzer.

If a careful analysis of the movement is made when it responds to the natural or unconditioned stimulus and this is compared to the movement produced by the conditioner, the movement is not the same. The learned movement has different properties. The learned act is not to be looked upon as a simple change by the addition or subtraction of something to or from the original movement. Rather it is a replacement of one form of movement by a different one.

The learned movement may become one which achieves a biologically or psychologically desirable end with less effort or energy expenditure and in shorter time. So in a very real sense through learning we recreate our worlds of things, space and movements to conform, as best they can, to the culture patterns in which we must live our lives.

Psychological Optics

—BY—

SAMUEL RENSHAW, Ph. D.
Ohio State University

OPTOMETRIC EXTENSION PROGRAM

METHODS OF STUDYING LEARNING AND HABIT

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Last month we considered the universality of learning and some of the difficulties encountered in framing a definition of the concept. Part of this difficulty arises from the fact that the clear definition of such a concept can be formulated only after a substantial body of experimental results have been secured. Fortunately, we have a very considerable body of facts relating to many specific questions regarding the most effective means that should be utilized in the control of the process of acquiring skilled movements. In this paper we shall describe for you the methods used in the laboratories for the study of the many problems relating to how a person learns, the limits of learning, the factors which influence the rate of learning, and such similar questions

There are no less than eight varieties of method or procedure which are used in studies of this kind. We shall take these up one by one and in the course of our description of these methods will attempt to bring out some useful facts relating to the control of the amount, rate, and limits of improvement through practice.

I. Direct Recording of Performance Output

Perhaps the simplest method of studying learning is the "learning by doing" method. Here a record is kept of the total accomplishment in any practice session and these are recorded and plotted For example in learning the telegraphic Morse code or in learning to typewrite, samplings are taken at regular intervals of the number of words or letters written or sent and received per unit of time

Such data yield an empirical plot of the course of progress, and learning is inferred from the gains in performance. The rate of learning is the slope of the curve. The main difficulty with such a consideration is that learning and performance are not co-variant. Performance may change considerably with no change at all in true learning; and learning can change considerably with no change in performance.

Before beginning any learning experiment, we must always decide which of two possible general methods we shall pursue. We speak of these as time-limit and work-limit methods.

In a time-limit method, time is kept constant and accomplishment varies with the skill of the subject. In a time-limit method the measure of performance is the number of problems solved, the number of sentences translated, the number of typewriter strokes which can be produced in a specified length of time. When we use the time-limit method we are emphasizing speed. Our primary interest is the number of completed errorless acts which can be produced per unit of time. It should be pointed out that in many human undertakings this is the least important factor to which we give consideration. For example, if we are attempting a reconstruction of visual habit, the emphasis is upon the reorganization of functional processes. We are interested in accuracy, precision, coordination and things of that sort.

When we use a work-limit method we emphasize the performance of complete and errorless acts, and the time required for the performance of such acts is secondary The fundamental distinction between the work-limit and time-limit methods lies in the fact that in the work-limit method our whole emphasis is upon a correct form in the executant function If an artist paints a picture, if a tailor fashions a

suit of clothes or if you are making a diagnostic eye examination, the important thing is to complete the job perfectly. The time required is secondary.

This distinction between work-limit and time limit methods is a very fundamental one. What may appear to casual observation to be the same experiment done under these two conditions becomes an entirely different thing if we utilize a work-limit method rather than a time-limit method. In the first instance, the problem itself is wholly different. In the second instance we must use quite different methods of treating our data. Let us illustrate this point by two examples. Let us suppose that a patient is undergoing orthoptic retraining in your office. Let us further suppose that you are recording his progress in terms of the unit of time. Assume that this patient has put in ten practice periods over a period of ten weeks and he exhibits 50% improvement over his initial status. What is the average weekly rate of improvement?

The answer to this question is not as simple as it appears on the surface. When we average time rates, we must use the geometric mean. The formula for this kind of average is as follows:

$$M_G - \sqrt[n]{(X_1 \cdot X_2 \cdot X_3 ---- X_n)}$$

The solution to the above problem is:

$$\sqrt[10]{1.5} - 1 = 4.1\%$$

which is the average weekly gain. The computation may be simplified by the use of the following formula:

$$\log M_G = \sum \frac{\log x}{N}$$

In the above equations N represents the number of practice sessions. $X_1 \cdot X_2 \cdot X_3$, etc. represent the attainment scores at each practice session. Note that the average weekly gain is the tenth root of the gain plus the initial status subtracted from the initial status. In other words a weekly improvement of 4.1% will increase the performance efficiency by 50% in ten weeks. Let us take a further example.

Suppose a subject gains 90% in skill in three months. The average gain per month is not 90 divided by 3 or 30% but it is

$$\sqrt[3]{1.90} - 1.0$$

which is 1.24 - 1, which equals 24%. At the end of the first month the gain is 100% plus 24% which equals 124%. At the end of the second month the gain is 24% of 124% which equals 29.76%, or the status at the end of the second month then is 124% plus 29.76% which equals 153.76%. At the end of the third month, the gain is 24% of 153.76% which is 36.24% which added to 153.76% totals 190% of the initial efficiency. This is another way of saying that the subject has gained in three months 90% in excess of his original skill.

Let us suppose that the same patient is being studied by the work-limit method in which so many complete and errorless acts are performed and at the end of this performance the total time for this accomplishment is taken. Let us assume that a school boy at the beginning of training is able to read four sentences per minute. The next week he reads six, then eight, ten, and finally at the end of the fifth week, he can read twelve sentences per minute. The sum of four, six, eight, ten and twelve is forty and five into forty goes eight times which is the arithmetic mean of the number of sentences read per minute. Sincere there are sixty seconds in a minute, sixty divided by eight gives an average of 7.5 seconds required to read one sentence. This is the arithmetic mean of the rates. Such a mean or average gives a wholly erroneous picture of what has happened. Rather when we are dealing with work-limit methods, we must use the harmonic mean. The formula for the harmonic mean is as follows:

$$\frac{1}{H} = \frac{1}{N} \sum \left(\frac{1}{m} \right)$$

In the above equation H is the harmonic mean, N is the number of practices, $\sum$ is the sign of summation and m represents the individual scores or measures. In the above example the proper solution of the problem "what was the average weekly gain in sentences read per minute by the boy?" can be solved as follows:

Weeks	Sentences read per minute	$\frac{1}{m}$	Seconds required to read 1 sentence
1	4	.25000	15
2	6	.16667	10
3	8	.12500	7.5
4	10	.10000	6
5	12	.08333	5
	$5\overline{)40}$ 8 $\frac{8}{60}$ = 7.5 sec. required to read one sentence. This is the arithmetic mean of the rates.	$5\overline{).72500}$ .1450 $\frac{1}{.1450}$ = 6.897 $\frac{6.897}{60}$ = 8.7 sec. required to read one sentence. The harmonic mean of the rates.	$5\overline{)43.5}$ 8.7 sec. required to read one sentence.

Notice that the average determined by the simple arithmetical mean gives a value of 7.5 seconds whereas the true average rate is 8.7 seconds according to the harmonic mean. The rate is 6.897 sentences per minute according to the means of the absolute times.

The error introduced in such calculations by the selection and use of the wrong kind of mean may lead to an erroneous conclusion particularly if the spread or scatter of the individual measures is large. It therefore becomes highly important in attempting to describe and interpret the effects of practice to select appropriate statistical procedures which conform to the exact statement of the problem and methods.

The rate of improvement in any learning function will be determined in part by the number and length of the practice sessions. The results of many experiments indicate quite clearly that often times, in learning, the way to gain time is to lose it. Many learning operations proceed far more effectively where three short intensive practice sessions per week are given than if daily practice periods are given. The length of the individual practice sessions is an important consideration. Often times a brief intensive practice of a few minutes is far superior to a prolonged session of many minutes or an hour. The general rule that distributed practices are better than massed practices has behind it the weight

of experimental evidence.

Many years ago William James proposed what he called the incubation theory. This states essentially that we learn to swim in winter and to skate in the summer. It is likely that true learning takes place not while we are practicing but in the intervals between practices. The proper control of learning means that the experimenter must be just as careful as to what kind of activities the learner engages in the recess periods between practice sessions as he is concerning the activities of the learner during the practice itself.

The term practice is often misunderstood. Merely to go through a specified set of motions cannot be regarded as practice. Many a beginning golfer for example has hacked away assiduously at the ball "practicing" two or three hours a day for an entire summer and if he has kept a careful record of his score, he learns to his dismay that he has improved little, if any. Practice in error, that is repeating a highly variable series of movements some of which point in a direction opposite to that to be ultimately attained, results only in the more firm fixation of weakness and inefficiency. The objective in any learning experiment is the achievement of correct form. Speed comes incidentally. The first consideration then should be: Set the stage in such a way that each practice session affords for the learner the most likely conditions for him to exercise the correct form of the movement you wish him to learn. There is abundant evidence to show that the number of practice sessions has little to do in determining the rate of true learning. Practice is the name we give to the fact that we are affording the learner conditions favorable for him to actively reorganize his attack upon the problem. It is not true that the more you practice the more rapidly you will learn. In fact beyond a certain limit the increase in the number and length of the practice sessions will lead to extinction.

It should be constantly kept in mind that frequently the skills which we seek to incorporate have to be learned by means of what Swift and others have called the law of the unconscious adoption of method. This principle merely states that the achievement of the form of a skilled act is hit upon more or less blindly or accidentally by the learner who keeps striving to get the "feel" of the unitary movement which to an observer may be quite simple but to the learner is usually very difficult to attain. We must constantly bear in mind that little or no learning takes place unless the learner maintains a sincere desire to improve and that he voluntarily strives to bring this about. Years ago it was said that it is the intense effort which educates. Learning, however, is something more than this. It is not only the intense effort exhibited by the learner but it is intense effort intelligently directed and intelligently expended.

Numbers of experiments have shown that learning proceeds much better where the learner practices "with knowledge." This means that if we plot or chart the course of improvement and show him frequently where he has come from, where he is now, and where he should ultimately arrive, the rate of improvement will be significantly better than if the practices are routinely expended and the learner is kept unaware of the course of practice. Careful and competent direction of learning, therefore, involves taking careful pains to control the attitudes of the learner and to help him by every possible means to understand clearly just what you want him to do. The course of learning is largely a matter of replacing the early stage of confusion and misunderstanding with a clear perception of what it is he is to do and what he must do about it. The gains in improvement are known to proceed in a saltatory fashion. They do not show constant and progressive increments. Consequently, the typical picture in a learning experiment is one in which as the practices are expended, periods of little or no observed improvement are followed by rapid jumps to new levels of proficiency. Part of the task of the one who controls the learning is to keep the learner encouraged during these periods of little or no apparent progress by showing him that after all these often discouraging periods of slow improvement are laying the ground for the more extensive gains which in most cases lie just around the corner.

Psychological Optics
—BY—
SAMUEL RENSHAW, Ph. D.
Ohio State University

Duncan, Okla.
OPTOMETRIC EXTENSION PROGRAM

METHODS OF STUDYING LEARNING:II

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In the laboratory we often wish to study and observe human learning so that we may describe the stages in its development and may arrange to control some of the determinants of the amount, rate and mechanisms of improvement.

Experiments are always made to settle issues which can not be resolved by logical thinking and talking. It is therefore quite necessary that one should have at least a fair acquaintance with the best literature on any problem before planning an attack upon that problem experimentally. There are a number of good books on human and animal learning. There are also a number of ones which I cannot recommend to you. The list which follows I have selected because I believe it is necessary to lay a firm theoretical foundation, if one is to attain even a fair appreciation of the many problems incident to the study of learning.

1. Holt, E. B., Animal Drive and The Learning Process.

2. Humphrey, Geo., The Nature of Learning in the Living System

3. Guthrie, E. R., The Psychology of Learning.

4. Tolman, E. C., Purposive Behavior in Men and Animals.

5. Lashley, K. S., Brain Mechanisms and Intelligence.

6. Hilgard, E. R. and Marquis, D. G., The Conditioned Response.

7. Pavlov, I. P., Conditioned Reflexes (Anrep, Tr.).

8. Koffka, K., The Growth of the Mind.

9. Murchison, C. (Ed.), Handbook of General Experimental Psychology.

10. Bartlett, F. C., Remembering.

11. Thorndike, E. L., Adult Learning.

12. Young, P. T., The Motivation of Behavior.

Naturally the very beginning of the study of psychological problems of learning and its control presupposes a clear understanding of many of the fundamental concepts of modern biology. Particularly is it necessary to know something of the modern developments in neurology and neuro-physiology. It should not be necessary to point out that 'learning' is not a physical process of lowering electrical resistance (or increasing conductance) across synapses. If it were, such a process of rigid and inflexible canalization would produce a kind of machine-like stereotypy in the behavior of living things the only result of which would be to unfit them for the rapid necessary readjustment to new and changed conditions of life which is the earmark of all true learning. Learned acts, by the very antithesis of the above, are not rigidly set patterns of nerve conduction and muscular or glandular response. The proof of this statement lies in the fact that when a skilled movement has been learned, the learning is not localized. If a movement is learned with the right hand, the left hand which was not practiced at all in the learning series may show 75% to 90% as much improvement as the right. If you learn to trace a maze pattern with the forefinger of your right hand, you will automatically have learned to make the movement almost equally well with your left foot. In fact, when you learn a skilled movement with the right hand and when you consider all nervous, muscular, tendinous, articular, vascular and other tissue components it is really quite difficult to conceive how the same, precise, identical movement can ever be consummated twice even though we repeat

it in essentially the same form a million times

No one can deny that the better we know the physical adjustory mechanisms of the body the better will we advance in our study of the problems of learning. But also no one will deny that learning is a distinctive psychological problem, which is to say that no matter how much anatomy, physiology and physics we know the solution of the problem must lie in the province and methods of experimental psychology.

Method II. Control Conditions: Mazes

The maze was at one time a garden in which a series of intricate pathways flanked by high hedges presented a complex problem for a person to find his way to an objective usually located in the center of the garden. The system of paths always contains a number of blind alleys or culs-de-sac together with the true paths. The object, of course, is to learn by the most direct true path, with the avoidance of any blind alley entrances, to find one's way to the goal. It is said that the ancient kings amused themselves and their ladies from the balcony of the castle at the futile attempts of the feeble-minded court fool to find his way out of an intricately planned maze. One king is said to have taken this means of amusing himself with a beautiful courtesan in a small garden house at the center of a complex maze safe from the intrusion of an irate but none too intelligent wife.

The maze has been used in many forms for the psychological study of learning. It provides a means by which we may control the practices of the learner under standard conditions and may study and observe the stages in which errors are eliminated and the problem is eventually mastered.

Many ingenious forms of mazes have been developed for studies of both human and animal learning. Sketched below is one plan known as a high relief finger maze.

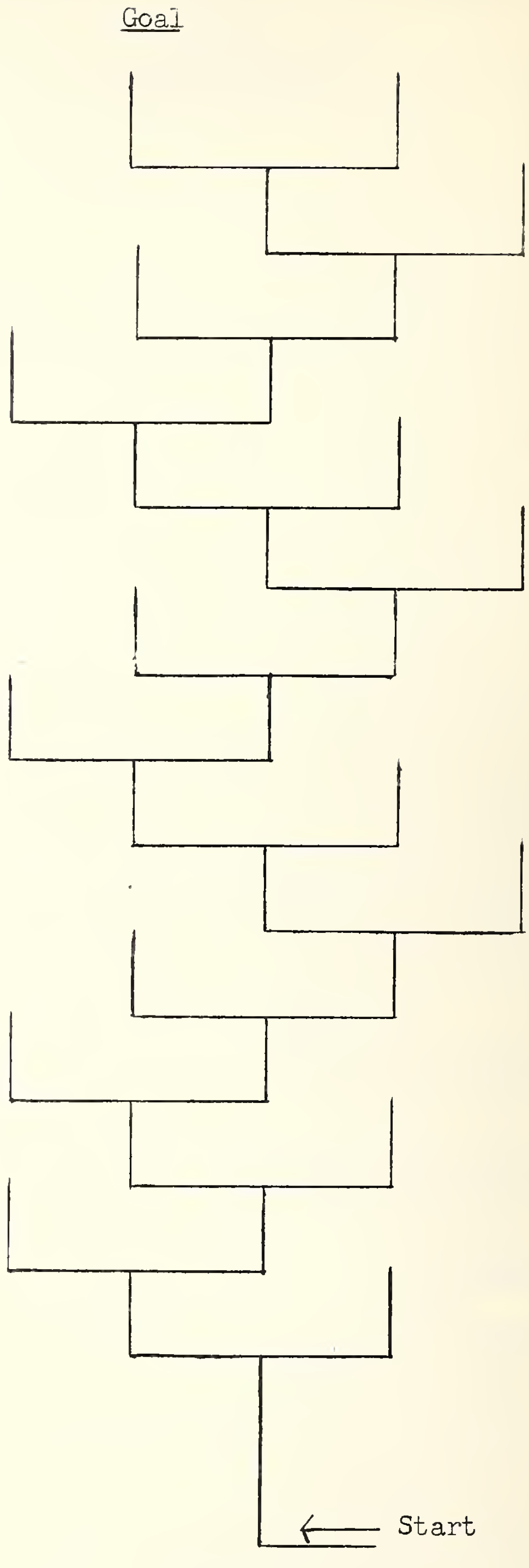

Figure 1.

Small holes are bored in a ply wood board of suitable size generally about two feet square and through these holes, wires are sewed to constitute what is known as a multiple-T arrangement of the maze. An examination of this figure will show that the subject merely has to learn a series of right and left turns which come in a random order. In case of small animals such as white rats, this is a difficult learning task and usually requires a large number of practices before it is mastered. When animals are used the multiple-T's are, of course, so constructed that the pathways lie between sideboards deep enough to prevent the animal from climbing out of the run ways. Human learners usually operate the high relief finger maze blindfolded or with the maze obscured by a screen. The instructions to the learner previous to the first trial usually include only enough to insure that he knows what is wanted of him and how he shall proceed. Such matters as the extent to which he may use language to aid him in minimizing the number of trials is left to the ingenuity of the learner. Records are generally kept of the total time for each trial from the beginning to the successful completion of a single run and the number of blind alley entries or errors is also recorded. In some instances automatic electrical recording devices enable us to record the speed of the runs, total time spent in any blind alley, the amount of retracing done, and etc.

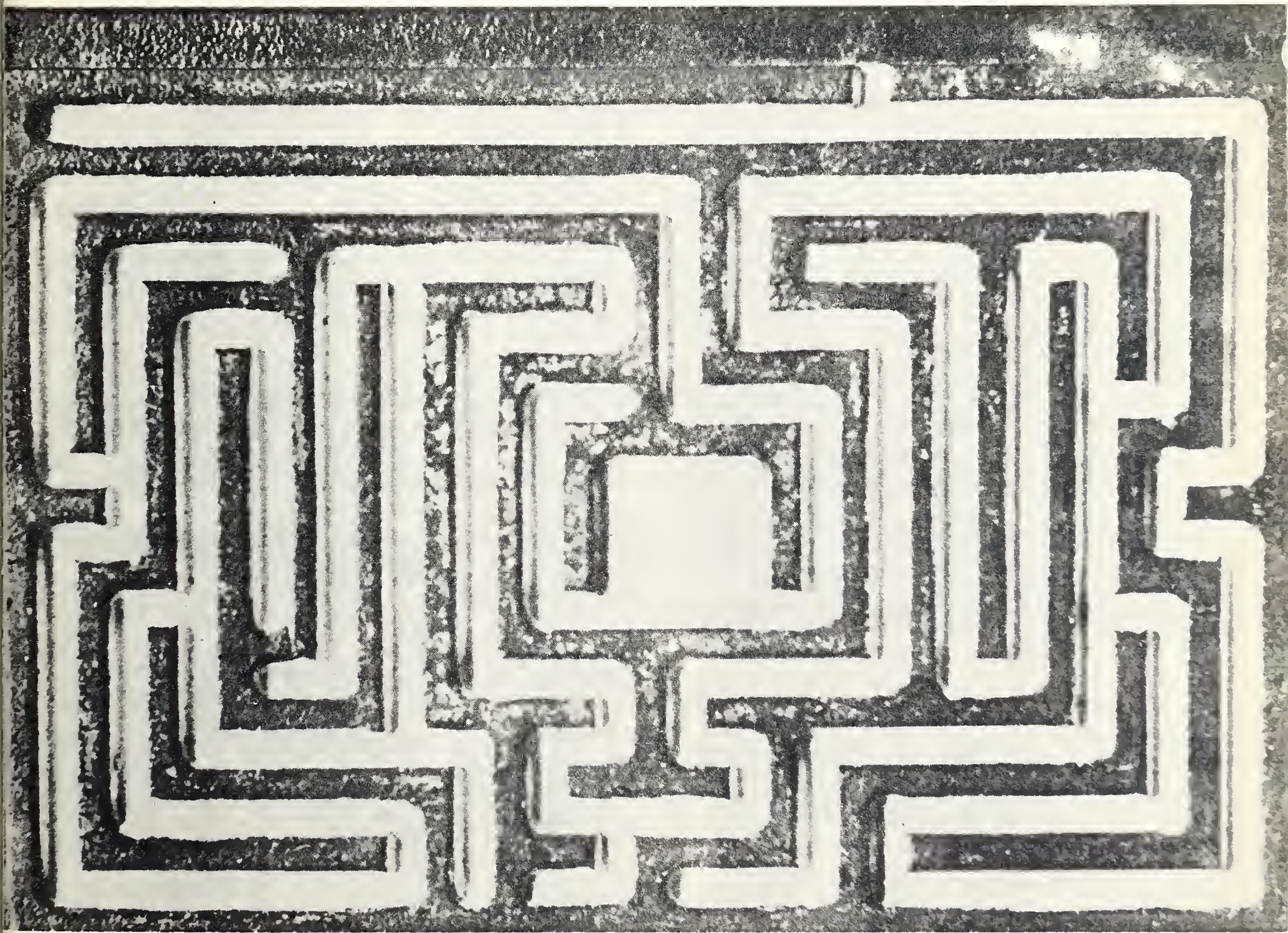

Figure 2

Figure 2. is a reproduction of the ground plan of a Meyer finger maze. This is an iron casting the face of which contains a number of ridges between which the true path and the blind alleys lie. The subject places his finger in the U-shaped compartment in the center and his task is to find his way to the exit which is the small opening at the top outside ridge. The subject, of course, is blindfolded or the maze is concealed from sight by being placed in a cubical screen. Practice sessions consist of a specified number of trials or runs per day. The maze is considered learned when the subject is able to complete three consecutive errorless runs in a minimum time which is usually empirically determined by the experimenter running the maze himself with the eyes open and true path clearly marked.

An interesting form of this type of maze is known as the Miles two-story duplicate maze. This is a box-like arrangement containing two identical metal maze patterns, one on the floor inside and the other on the top of the box. The sides of the box are made of black curtains. The maze inside the box rests on a circular platform which can be rotated so the learner must trace with his finger the inside maze which can be placed by rotation in any desired position eccentric to the one he sees at the top of the box. This permits us to study the role of the visual control of hand movement; also we may investigate such problems as that of habit interference. If this maze is learned with the inside pattern rotated to a position 90° to the right, we may then, as soon as this habit has been adequately learned, change the position to 90° to the left and we may observe and measure the number of trials required to master the pattern in the new orientation.

Sometimes a wood or metal stylus is substituted for the finger in order to reduce the tactual cues in traversing the slots or grooves. Many ingenious devices have been developed by various experimenters for delivering electric shocks for wrong movements, for preventing retracing and for exercising various other means of control.

A careful protocol is kept at the conclusion of each trial in which is recorded all of the observations made by both the subject and the experimenter during that particular trial. This becomes very important in the final analysis and interpretation of the learning data. Before any trials are made the experimentar must carefully plan his experiment with regard to the number and length of the practice sessions to be given daily, the length of the rest periods between such practice trials, the kind of instructions he gives to his subject, the control of motivation; and he must perfect himself in the handling of his apparatus, his method of record keeping, and in the control of all conditions surrounding the experiment. These will be determined largely by the nature of his problem. If he is interested in determining the relative influence on speed of learning of two different methods, he must then plan to use a control group; and he must use a sufficient number of subjects in the experimental and control groups to give him enough data to enable him eventually to draw from the data some valid conclusions. If he is studying the influence of some factor upon the learning process itself, he will perhaps elect to use a smaller number of subjects and make a more intensive analysis of the effect on the process of varying the learning conditions.

When the experiment is finished and the data is all at hand then the most interesting part of the venture begins. This is the analysis and interpretation of the results. This is the stage which demands even greater knowledge and skill on the part of the experimenter. It should be emphasized, as we have pointed out previously, that the records in terms of times and errors are performance indicators. Since learning and performance are not co-variant, we must deduce from the performance records the characteristics of the true learning function. In order that you may learn something of the method of treating and interpreting such data, I shall give you the records of the first thirty trials made by a student in learning a finger maze similar to that shown in Figure 2. above.

Trials	Time in seconds	Log/time	Errors
1	85	1.92492	7
2	49	1.69020	2
3	45	1.65321	4
4	43	1.63347	2
5	47	1.67210	2
6	97	1.98677	6
7	83	1.91908	5
8	61	1.78533	5
9	98	1.99123	4
10	59	1.77085	4
11	43	1.63347	3
12	35	1.54407	1
13	30	1.47712	0
14	30	1.47712	0
15	25	1.39794	0
16	54	1.73239	2
17	22	1.34242	0
18	22	1.34342	0
19	26	1.41497	0
20	21	1.32222	0
21	19	1.27875	0
22	21	1.32222	0
23	22	1.34242	1
24	20	1.30103	0
25	23	1.36173	1
26	20	1.30103	1
27	19	1.27875	0
28	17	1.23045	0
29	18	1.25527	0
30	18	1.25527	0

Take a piece of millimeter ruled graph paper. Draw two coordinate axes $\underline{y}$ and $\underline{x}$. The $\underline{y}$ axis or ordinate is the vertical line to the left and the $\underline{x}$ or horizontal axis, called the abscissa is placed at the bottom of the sheet. Lay off on $\underline{y}$ a scale designated "Performance time in seconds" running from 0 to 100. On $\underline{x}$ plot the number of trials from 0 to 30 or 40. Take the above numbers. On trial number 1 on $\underline{x}$, go up on $\underline{y}$ to the point which represents 85 seconds. Place a dot here. Do the same for each of the thirty entries. Join these dots with a thin solid line. You now have a graphic picture of the course of improvement of this function during the thirty practice sessions. Note that the improvement seems rapid and steady during the first four trials or practices and that during the next eight trials there followed the type of thing usually found in learning experiments, that is, as practice continued the learner performed more poorly instead of better and it was not until the eleventh and twelfth trials that he equaled or exceeded his performance on trial number 4. He continued to improve until trial 15 when he suddenly regressed but quickly recovered on number 16. Note that from the 16th to the 30th trial, the rate of improvement was quite slow and gradual but unmistakable. Here we should bear in mind that in interpreting a plot of this type the farther to the right we go the more significant each unit of improvement becomes so that it is probably entirely erroneous to say that such a curve indicates that the learner improved rapidly at first and that the rate of improvement slows down gradually toward the end of the practice series.

It should be pointed out that your plot of these figures is purely an empirical or non-mathematical representation of the data. Now take another sheet of millimeter ruled graph paper. On the $\underline{y}$ axis arrange a scale which will appropriately represent the logarithms of the times for each trial. On $\underline{y}$ plot the number of trials directly as before. Place a black dot at the proper coordinate point for each entry. Take a piece

of black thread and stretch it so that the dots fit the straight line of the thread in the best possible way, that is, so that the number of dots which deviate above the thread is approximately equal to the number which deviate below it When you have thus found a suitable slope for the straight line of best fit by the method of inspection, locate this position and draw a straight line with a pencil and a ruler The equation of this straight line can now be calculated rather easily. This equation is

$$y = mx + b$$

in which $\underline{m}$ is the tangent of the angle made by projecting the line you have just drawn until it intersects both $\underline{x}$ and $\underline{y}$. $\underline{m}$ is thus a measure of the slope of the best fitting line and may be taken as representing the rate of improvement exemplified by the logarithms of the times of the practice trials. When we recall that the points which deviate significantly from this line are caused by all manner of factors capable of momentarily influencing performance but which are transitory in character and do not permanently affect the course of true learning, we can see that the plot we have just made more truly indicates the kind of thing which actually took place in the learning experiment. In other words we may strongly suspect that the true learning curve is actually an approximation to a straight line of small gradient and that the steepness of this gradient is the true index of the rate of improvement.

Psychological Optics
—BY—
SAMUEL RENSHAW, Ph. D.
Ohio State University

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OPTOMETRIC EXTENSION PROGRAM

THE CONDITIONED RESPONSE

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Part I
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Among the various methods of studying human and animal learning the method of conditioning of responses is one of great interest and importance. In this paper we shall sketch briefly the history, techniques and types of conditioned responses and later something about recent experimentation and theory.

In the past forty years a substantial literature has grown up reporting large numbers of investigations using these methods. Conditioning experiments have been made upon every kind of living organism from white blood cells to man. Because of the limitations of space it will be possible for us to treat only sketchily a few phases of this literature.

The precise origin of the conditioned response doctrine is practically impossible to localize. The phenomenon known as psychic secretion was observed and described by the early physiologist and medical men. A great deal of myth and confusion existed regarding the work of the digestive glands prior to the work of Ostwald, the chemist, and to the observations made upon the celebrated case of Alexis St. Martin a French-Canadian trapper and hunter who suffered a severe abdominal gunshot wound which when healed left him with a gastric fistula through which stomach movements and gastric digestion could be directly observed. The clean cut descriptions of a young American physician are classics in the literature of this field.

In 1902 a Russian physician and physiologist, Ivan P. Pavlov read a paper on the work of the digestive glands before a medical Congress in Madrid. In it he described those functions of the buccal glands occasioned by the sight and smell of foods. He pointed out that the natural or unconditioned reflex secretion of the parotid, submaxillary and sublingual glands was a response to contact stimulation - the presence of material food substances in the mouth. The sight or smell of food at a distance was an artifical means - a conditioned method - of eliciting these responses. Originally, the presence of sight and odor stimuli would evoke movements of the head and body muscles, but only by a process of training were they made to take on the surrogate function of serving as effective substitutes for the natural or unconditioned stimulus in producing the secretory and other movements of the digestive mechanisms. This modification of native reflex mechanisms was held to be a function of brain structures and Pavlov reasoned that if he could find out the facts by careful experiments as to how these "artificial" reflexes were established he would, in so doing, have a powerful tool which would enable him to probe objectively by the methods of natural science into the complex and poorly understood higher mental processes postulated to be functions in the brain of elaborate systems of conditioned responses.

Here was something new; an objective and controllable method of analyzing processes which had, thus far, largely been studied only by the more or less unsatisfactory 'subjective' methods of introspection. Would it prove to be the key to unlock the mysteries of the dark continent of the all-important functions of the sensory-cerebro-motor mechanisms of the vertebrates, including man himself? Would it simplify the baffling complexities of the symbolic process of learning, memory and thinking? Here was a colossal challenge. Here was a new development of concept and method which promised to throw new light on the age old problems of the relations of the physical and the mental. Perhaps from the researches along these lines there could be formulated a reconciliation and a resolution of the differences and the bickerings among scholars interested in one or the other aspects of the dualistic world of matter and of mind.

Couriously enough here in America in the same year that Pavlov read his Madrid paper, two psychologists accidentally stumbled upon the same general principle, but in a somewhat different way. Twitmeyer in Pennsylvania and Stratton in California were working independently on the patellar tendon or knee-jerk reflex. When a pendulum hammer strikes the patellar tendon the knee-kick reflex is elicited. If a bell is sounded a little before or during the stimulation of the tendon, the extent of the excursion of the limb is enhanced. Something went wrong with the apparatus. The bell sounded as usual to reinforce the stimulation of the tendon, and the release of the hammer failed. But the kymograph record showed that the movement of limb occured virtually as if the tendon had been stimulated. Clearly here was a case of "conditioning" or something closely resembling it. Apparently neither investigator followed up the lead and so perhaps rightfully the credit for first conceiving the concept and the experimental program and the theoretical framework belongs to Pavlov.

Salivary reflexes in dogs were the objects of the early experiments and may be described as typically illustrative of the various forms of conditioning. By a simple bit of surgery the papilla of the duct from the parotid gland is transferred to the external cheek on one side and a small cup or funnel is sealed over the opening to catch the serous secretion. A tube from this is connected to a glass manometer placed horizontally and calibrated in 1/100 milliliter units. Each drop of saliva displaces the liquid in the manometer thus by a measured amount, or a drop-recorder may show on a kymograph or paper tape the rate and amount of flow.

The animal was placed in a stanchion on a table in a quiet isolated room and observed from without, all stimuli being administered by the experimenter from outside by pneumatic or electrical means. All extraneous and uncontrolled stimuli were rigidly avoided, including the chief disturbing one of these - the presence of the experimenter himself.

A conditioned response of the simple type is established as follows. A hungry dog is placed in the stanchion. A record of the normal or unstimulated rate of salivary flow is taken. A pure tone of 256 cycles per second is delivered to the experimental room through a speaker for 5 seconds and the rate of flow is noted. Usually there is no change. The tone is now given and immediately following this a moistened meat powder and bread mixture is supplied mechanically and the dog eats. This tone-food sequence is repeated, usually from ten to fifty times, and the tone alone now induces the same or almost the same rapid increase in drops of saliva per minute, produced originally by the food. The tone has taken on the signalling power originally possessed only by the meat in the mouth. This latter - a function mediated by subcortical neural mechanisms - has been excited by the excitation of cortical visual and olfactory centers which would produce no such effect before the training. Conditioning was thus to be regarded as a form of opening up new intercalary paths of conduction thus functionally conjoining the cortical centers of sight and smell with the sub-cortical nuclei from which effector discharges reached the oral digestive glands. Food is the natural or unconditioned stimulus to reflex secretion. The tone is the conditioned stimulus and produces the conditioned salivary response.

The tone is sounded for longer and longer periods day after day until it reaches 30 or even 60 seconds. The total secretion during this period is taken as a measure of the strength of the reflex.

Suppose a fly gets into the experimental room and buzzes around the dogs head. Such an afferent slight change in the environment may lessen materially or even stop the increase in salivary flow to the tone. This Pavlov called external inhibition. It overwhelms the food-reflex because the fly evokes the stronger competitive investigatory reflex. But if the fly comes back again and again the strength of this inhibitory influence rather quickly disappears. It is to guard against external inhibition that rigid isolation and control of the animal's experimental environment is maintained.

Conditioned responses in human subjects can be established with less carefully controlled conditions. If a puff of cool air from a tube is directed at the cornea

from the side and at the same time a small buzzer is sounded, the lid closing reflex may be conditioned usually after twenty to thirty pairings of the conditioned and unconditioned stimuli. The buzzer sounds and the eye winks. If now we continue eliciting the movement of the lid, recorded by a silk thread attached to the upper lid and running to a polygraph recorder, by the buzzer alone it will be noted that the lid movement grows less and less and may finally disappear. This is called extinction.

In order to keep the conditioned response working it is necessary to introduce again occasionally the puff of air or unconditioned stimulus along with the conditioner, otherwise the conditioned response gradually weakens and becomes self-extinguished. This instability of true conditioned responses is one of the reasons why it is difficult to accept the principle as the basic underlying principle of all human and animal learning.

Experimental extinction has numerous practical uses. For example if the baby sucks his thumb an effective "cure" is often accomplished by forcing him to suck the thumb <u>voluntarily</u> for a prolonged period. If you write <u>hte</u> for <u>the</u> on your typewriter, write the wrong letter order a hundred times voluntarility or deliberately and there-after you will most likely not make the same mistake again. Extinction was perhaps the basis for the "cures" for alcoholism in which the patient received whiskey in his breakfast coffee, on his grapefruit, sprinkled on his pillow, etc., etc., for days.

It should be emphasized that great caution should be used in employing extinction in the treatment of stuttering or similar sorts of things. Other uncontrolled forces may conspire to produce an enhancing effect rather than extinction.

When a reflex is extinguished it may reappear the next day, but it is now more easily re-extinguished. If it is again restored after rest it can be extinguished still more rapidly. Finally it will remain extinguished. In this case however it is not without influence on the dog's nervous system. For if the extinguished stimulus is presented and later conditioning tone is presented, no salivary flow-increase is noted. The extinguished tone has been associated with no food and its effect has become inhibitory. This effect lasts long enough to block the excitation from the food signal. Pavlov called this phenomenon successive inhibition.

Sometimes summation may be exhibited in conditioning experiments. If the lid is conditioned first to a buzzer, then to a touch on the skin, this latter is called second order conditioning. The higher vertebrates may be carried to several orders of conditioning. In such a case as the above if the buzzer and touch are given simultaneously there results a movement much greater than that produced by either stimulus acting alone. A little reflection will show the importance of these two principles in conditioned fears, for example. The mechanism is here to provide for the shift of fear of the dark to fear of the child's red headed nurse and to any red headed person and so on.

It is easy to see that in persons who are weak and unstable from disease or from poor inheritance or faulty nutrition the soil is fertile for the conditioned generation of all manner of prejudices, fears, and irrational transfers of signification.

But let us look at a further important phase of the conditioning process. This has to do with how we develop discriminatory responses.

If the dog has been conditioned to respond positively, that is with marked increase in parotid secretion, to a tone of 256 cycles and we sound a tone of 300 cycles, what will happen? How specific is the stimulus? The answer is that tones of 300,435, 512 or 1000 cycles will all produce the same positive response. The conditioned response is at first wholly non-specific. This is a most important fact psychologically and it goes way beyond the limits of the conditioning concept. Our perceptions are similarly generalized and non-specific in their original states. Specification comes as the result of a process of training. I have emphasized this fact in previous papers.

Now if we give the tone 300 followed by no food and the 256 tone followed by food enough times finally the 300 will no longer produce the positive response. If we work back from 300 to 290, to 280 to

270, and so on we may finally arrive at a state where the 256 gives a sharp positive response but, say, 258 gives no response.

In the course of such experiments made to discover how finely the dog could discriminate between small pitch differences an interesting and important discovery was made. If the dog was given a tone of 258 to which he gave no response and 256 which was positive and then 257 was tried, for example, and it so happened that this difference of one cycle was below the animal's differential pitch limen, the animal suddenly began to drool saliva from his mouth. He became petulant, ill tempered, nervous in the extreme and was completely unfitted for further experimentation perhaps for months. An experimental neurosis - an artificial "nervous breakdown" - had been established. Animals must not be forced to make discriminations beyond the tolerable limits of ability.

We have observed a similar sort of phenomenon in our work on acuity training. If a new subject is forced to try to resolve the test object beyond his distance capacity we have seen them complain of frontal headache, dizziness and vertigo, nausea necessitating no further work on that day. In all such training the safe rule is to take them slowly and not attempt to crowd the limit of discrimination.

Obviously the child in school who reads, spells and adds poorly finds himself each succeeding day in deeper and deeper troubles of this same kind. Blocking and emotional states are seen in almost every case.

It is not impossible that prolonged visual effort at the near point may induce a quite similar type of inhibitory blocking leading to surrogate concessions, suppressions, amblyopia, etc., or to some other type of satisfactory escape. The whole question of the extended maintenance of a tonic or postural tetanus and its reciprocal effect upon concurrent sensory and phasic movement mechanisms in the same anatomical region needs to be carefully examined.

Next month we shall continue our consideration of other important phases of conditioning; delayed and trace conditioned responses, negative conditioning and disinhibition, irradiation and similar phenomena.

Psychological Optics

—BY—
SAMUEL RENSHAW, Ph. D.
Ohio State University

Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

THE CONDITIONED RESPONSE
Part II

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'here are several other important types of onditioning phenomena. In this paper we hall describe three or four of them and onclude with a consideration of some theo- etical and practical phases of the problems aised by these experiments.

et us consider the delayed and trace types f continued responses and the important henomenon of disinhibition.

'avlov and his students early observed that t was possible to delay the onset of in- reased salivation. If a continued response o a tone of 300 cycles has been regularly voked by a tone sounding for 30 seconds, he latent period (from the beginning of the one until increased flow of saliva is ob- erved) was of a comparitively short dura- ion, usually from 1 to 5 seconds. Now if he duration of the tone is gradually in- reased day after day until it becomes as ong as 180 seconds, the latent period, that s the onset of increased salivary flow, will radually lengthen also until it may be as ong as 2 minutes when the tone is continued or 3 minutes before food is given. This is alled a delayed conditioned response.

avlov interpreted delayed conditioning some- hat as follows: The conditioned stimulus for ood, namely the tone, is not the only stimu- us signal to which the animal is reacting. he total duration, or the time through which he tone sounds, is also a positive stimulus nd the dog soon learns that it is wasteful nd inexpedient for the salivary glands to tart functioning until about the proper a- ount of time has elapsed. Numerous investi- ators have shown that this time sense may be eveloped to limits of accuracy such that the alivary flow will start a few seconds before he end of even a relatively long laten peri- d. Further theorizing proposed originally by 'avlov presumes that the tone and the temporal rocess excite separate foci of excitation in he brain. These regions at their boundries re at first sharply separated. The sensory ignals are restrained from issuing into a mo- or discharge until the spread of the excita- ion, perhaps through electrical leakage, auses them to overlap and reinforce each other. he function of double stimulation, therefore, s to produce the state in which the tone stimulus is temporarily inhibited by the concurrent activity of those processes concerned with time discrimination.

If, during this period of delay, a bright light is flashed or a loud sound puts in appearance, the period of delay is immediately abolished and there will be a sudden onset of salivary flow. This is the phenomenon of disinhibition. It may be regarded as a process of inhibiting the inhibitor.

The phenomenon of disinhibition provides us with a most interesting conception. It probably is the means of accounting for some of the alleged miracles which are observed to happen in the world. Let us suppose that a person develops an hysterical block which may involve the inability to move a leg or an arm, or which may involve complete suppression of vision in one eye. If the house catches on fire, the person may galvanize into immediate activity, even to his own surprise. When the physician advises his patient to take a trip to Florida, to Sun Valley, or an extended cruise, he does so realizing that the change of climate which he recommends may serve to place the patient in a new environment which may serve the double purpose of removing the maintaining conditioned stimuli which produce the block and at the same time provide an active disinhibition.

Krasnogorski has discussed the question of delayed response at considerable length. He describes the process by the term "loading and discharge." The principle is of the highest order of importance. We see something today and the traces from this experience left in the central nervous system set us to respond differently at some later date. Experiments have shown that different animals, and indeed different persons, show wide variation in the length of the delay period through which the trace can maintain its effectiveness. Delayed responses can be made by certain species of animals only after a few seconds. Others may delay for several minutes. In the case of human beings, the period of delay may be extended for hours, weeks, months, and probably years The mechanism of delay in the case of the higher cortical animals may be mediated through the function of language.

We have repeatedly emphasized the great importance of such conceptions as set, drive, motive, incentive, purpose, etc. The above described phenomena give us a neurological mechanism which has been proposed as an objective basis for these processes. One thing we should bear in mind: Every stimulus and response process is set on a background of previous response determinats and these may strongly influence the course and limits of the reactance; they may be more effective than the "stimulus" of the present moment, whose function is a trigger which sets off a response.

Let us now look briefly at another type of conditioned response phenomenon. We select for this experiment a dog which has had no previous experience with auditory conditioned responses. We shall continue to use a tone of 300 cycles. The tone is sounded for 5 seconds and after 5 seconds of silence food is presented. Soon the tone itself produces no saliva, but during the silent period, saliva starts to flow slowly at first and increases in rate until the maximum is reached, which is at about the time food is presented. Then, just as in the previous procedure for the establishment of the delayed condition response, the food is given 10 seconds after the cessation of the tone, then 15 seconds, 20 seconds, etc., until as many as 3 minutes elapse between the tone and the food. As this period gradually increases, there is a corresponding increase in the length of the latent period. According to Pavlov, in this case, it is a trace of the excitations in the brain produced by the tone which is associated with salivation rather than the actual tone itself. During the silent period this trace gradually diminishes but is still present to some degree at least when food is given. An important characteristic of the trace conditioned response is its known-specificity. If a tone of 1024 cycles is presented after a 3 minute trace to the tone of 300 cycle tone, it was found impossible to train an animal to distinguish between the traces of the 2 tones. Further, if the trace response to the 1024 cycle tone is extinguished by withholding the food, the salivary response to the tone of 300 cycles disappeared too. Pavlov theorized that the excitation in the brain in the case of the training tone was limited to a small active region of the cortex, which spreads or irradiates over the surface of the brain and thus forms connections between many points in the brain and the strictly localized "center" for salivary secretion.

The phenomenon of irradiation became the basis of another curious phase of conditioning. During the course of the many experiments made on delayed and trace conditioned responses his experimenters complained that the dogs soon got drowsy often fell into a sound sleep a little while after the tone started to sound. This was annoying and in order to avoid this difficulty they tried experimenting with younger, livlier dogs. These, too, went to sleep as rapidly as the older ones as soon as the period of delay was extended beyond a certain limit. This started Pavlov to thinking about the probable mechanism of sleep. He reasoned that in the delayed response the cortical inhibition which forestalls the flow of saliva before the end of the 3 minute period is a "little local sleep" in one restricted region of the brain. At first this is limited to the tracts excited by the auditory stimulus, but after a while if no other stimulus comes to inhibit the inhibitor this local sleep irradiates to adjoining regions and finally may envelope the whole cortical area. Thus sleep is but a special instance of the inhibition-irradiation sequence.

It is impossible for us to describe here in a limited space all the interesting experiments which have been made in the field of conditioning. We have given you enough to show that it is possible by objective methods in the laboratory to study many phases of what seem to be intricate sensory-cerebro-motor functions. Color vision in animals may be determined by conditioned response methods, for example: If a dog is conditioned to respond positively by raising a paw when a red light of wave length 660 mu mu is shown to him, and if he is made negative to green but never differtiates red and green, we may conclude that he possesses no mechanism for red-green vision.

Conditioning work with humans is even more difficult than it is with dogs because it is more difficult to exercise with them the precise experimental control demanded

in such experiments. However, we have frequently conditioned the lid closing reflex to a puff of cool air on the cornea upon the sound of a small electric buzzer. If a silk thread is attached to the upper lid it may be led over a pulley system to a kymograph so that a record may be made of the movements of the lid. As soon as the lid responds positively to the buzzer, omitting the puff of air, we have then established a primary or first order conditioned response. If we now select a small spot on the back of the left hand and stimulate the skin with a light touch concurrently with the sound of the buzzer, we may soon establish second order conditioning so that the buzzer sound may be omitted and the touch on the hand will produce the movement of the lid. Culler and other investigators have shown that in both dogs and human subjects higher order conditioning is entirely possible. How far this process may be continued is at present unknown. Watson and others have called attention to the fact that most of our fears, food prejudices, and personal aversions are probably traceable to instances of this very kind of thing.

A consideration of these possibilities must again reemphasize the importance of case histories or the etiology of the situation whenever a patient consults you regarding any anomaly of vision.

Next month we shall summarize some of the criticisms of conditioning and then proceed to the problem of the acquisition of skill.

Psychological Optics
—BY—

SAMUEL RENSHAW, Ph. D.
Ohio State University

OPTOMETRIC EXTENSION PROGRAM

CONDITIONING AND LEARNING
Part III

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In the two previous papers in this series an attempt was made to describe some of the forms of the conditioned response, how these are established experimentally, and to set forth some of their characteristics. It now becomes necessary to examine the doctrine of conditioning as a theory of learning in critical vein, particularly with the question of its adequacy or inadequacy as a working hypothesis for what we do in visual training and retraining.

It is simple to talk of "reconditioning" a squinter, a suppresser or a myope when this term connotes merely that we have taken certain steps to replace an inadequate or inexpedient mode of response to the visual environs by a more effective and acceptable one. No one can seriously quarrel with the use of any term which merely conveys to another person the fact that <u>something</u> has been done, or more properly <u>several things</u> have been done, to produce a better functional state.

The difficulty comes, however, when the term conditioning or reconditioning is taken at its face value as the scientific procedure which was employed; and more when the end product is critically examined as being a function of the application of the true principles of conditioning.

Few, if any, of the early advocates of conditioning as the basic principle in learning are now willing to accept the original theoretical formulation of conditioning. Hull, Humphrey, Guthrie, Culler, Tolman, Liddell, Winsor, Borovski, --may be cited to name a few. Pavlov, in his last few years, printed an article in the Psychological Review in which he assailed the treatment his doctrine was receiving at the hands of leading American Psychologists.

Is the original theory of conditioning a satisfactory and adequate one upon which to base a generalized theory of human learning? Is it a safe model for building procedures for the development or transformation of visual skills? Is it therefore true to speak of the "reconditioning" of stereopsis, or of increased acuity or visual form discrimination, etc?

Let us first examine the framework of the original theory, and some of the criticisms which scholars have leveled at it.

In previous papers I have pointed out the well-known distinction between forms of behavior described as (a) molecular, and those classed as (b) molar. In the first class we might group such functions as muscle twitches, reflex movements involving perhaps a single level of the central nervous system, such as parotid salivation, eyelid closure, etc. In the second class we should place such functions as the binocular perception of depth and distance, of form and movement, or the memorizing of a poem or the acquisition of a manipulatory skill.

Even when we try to limit the doctrine to the view that conditioning applies to strictly molecular or elementary physiological processes, construed as components in more complex acts, which operate as a mechanism for establishing new coordinating and correlating paths of connection in the central nervous system, we get into trouble.

Land and Olmsted (American Journal of Physiology, 1923, pp. 65, 603-611) conditioned to a buzzer the flexion (avoidance) reflex elicited at first by an electric shock to the left rear leg of a dog. They then hemisected the cord at the first lumbar vertebral level <u>on the opposite</u> side. They found that the conditioned response to the buzzer was no longer present. The cutting of the half of the cord, they reasoned, interfered with the afferent paths from the original unconditioned

pain stimulus produced by the shock. To prove this, they made further experiments in which they established a conditioned response for which the unconditioned stimulus was pressure on the skin. They then hemisected the cord on the opposite side at both lumbar and cervical levels and found no interference. In other words for the conditioned response to take place, pathways for both the conditioned and the unconditioned stimuli must be intact.

Further, it has been observed again and again that conditioned responses cannot be maintained unless there is repeated pairing of the unconditioned ("natural") with the conditioned ("artificial") stimulus. If a function thus is instituted by training and after a lapse of, say, two years, with no such condition fulfilled it still operates smoothly and effectively, it is almost certain that this function is not a true conditioned response. In our laboratory we have noted that stable increments of acuity remained approximately two years after training not only with no decrement but in some cases with greater resolution than any attained at any stage in the original training series.

Last summer I was privileged to retest a subject who had been trained to high proficiency in the rapid perception and memory for digits five years previously --and there had been no loss in the skill even though there had been no intervening practice. The pattern of conditioning just does not fit these instances.

Another objection turns upon the difficulty, refractoriness and failure to condition certain classes of functions.

In spite of certain claims in literature, there are about equally valid claims that the iridic reflex has never really been conditioned to auditory or tactual stimuli. One investigator (Lynn Baker) claimed it could be done if subliminal stimuli were employed, but others who repeated his experiments failed to confirm his results.

There is nothing in the doctrine or nothing known neurologically to contradict the possibility, but no investigator has, to the writer's knowledge, ever succeeded in establishing motor point conditioning. Over fifteen years ago, I tried diligently to condition a finger movement produced by a Faradic shock to a motor point on the volar forearm to both visual and auditory stimuli. In one instance over 20,000 pairings of buzzer and shock in many temporal and intensive relations gave absolutely no result whatever.

All molar behavior processes need external supports, frames of reference, for the facilitation and fixation of learning. In molecular acts like salivary secretion, breathing, etc., these are supplied internally by the organism itself. It has been pointed out repeatedly that a weakness of the conditioning doctrine was its failure to take adequate stock of the important facts of motivation, drive, set, etc.

Experimental animals are usually motivated by hunger, water, or other tissue deprivation. Otherwise, conditioning is difficult or impossible. But the essential "laws" of conditioning are but three, of which the first two are of limited importance: Primacy, Recency, and Frequency.

It is important to consider the principle of frequency or repetition as a mechanism of learning so far as it applies not only to conditioning, but to any theory of learning. In conditioning theory of the Pavlovian type, frequency implies that the essential condition for the fixation of the path of the conditioned stimulus to release the unconditioned response is essentially a matter of the number of times the two stimulus-response mechanisms have been operating in temporal contiguity. It is not necessary for them to be active simultaneously. It is only necessary that they be not separated by too great a lapse of time. The greater the number of repetitions of the pairing, the stronger will be the interlinking bondage of the two hitherto unrelated functions.

But it becomes clear that here we strike an inconsistency in the theory, or what seems to be an inconsistency. The decisive determinant of the strength of the response is a direct function of frequency, while at the same time, if frequency is extended ever so slightly beyond a critical limit, the result is not greater strength and stability of the behavior form, but the result is extinction. Such a consideration may not be regarded as contradictory if we assume that whatever the nervous mechanism of conditioned

reflex learning may be, it partakes of the nature of a reversible reaction and we must further assume that in the nervous system there is, up to this critical point a sharp fixed relation between the number of reinforcing stimuli and the conductance through the new internuncial pathways.

It might be well in passing to point out that the whole concept of reinforcement is neurologically vague and unsatisfactory because no one completely understands its mechanism even in the simplest cases.

Lillie had pointed out that "the total effect of any stimulation has no fixed relation, quantitatively or qualitatively to the direct physical effect produced by the stimulus at the point of its application. In many irritable systems with highly developed transmissive properties -- in, for example, the nerve fibres and muscle cells of the higher organisms -- the character and intensity of the responses are quite independent of those of the stimulus, provided the latter attains its threshold value. A full response involving the whole irritable element, results from either a weak or a strong stimulus. This is the all-or-none type of behavior which is found also in many physical systems in unstable equilibrium, and also in explosive systems or others in which chemical change is rapidly transmitted. In all such cases there is a release of stored energy, and the work performed by the releasing agent has no definite relation to the energy transformed in the resulting process." That is, the nervous system is a system for conducting weak signals and must never be regarded as a power transmitting device. It is this latter conception which is implied in the doctrine of frequency.

Frequency is important, but its importance lies in an entirely different direction. The term "frequency" means one of two things: either the number of stimulus opportunities, or the total number of completed consummatory responses. Conditioning theory pertains principally to the first of these principles. The second involves the consideration that the primary role of frequency is to provide the learner with a sufficient number of opportunities for revising and transforming his movements until the most satisfactory and adequate one has been hit upon. This process never proceeds steadily and gradually as the theory would imply, but always goes forward by leaps and starts. It is this fact of variance which forces us to conclude that an essential prerequisite for learning in any organism lies in the fact that the pattern or constellation of forces designated as the stimulus and the series of movements designated as the responses vary continuously, and it therefore is not probably true that in the strictest sense, repetition of identical patterns can hardly be conceived ever to occur.

Further damaging evidence against this doctrine comes from the experiments of Joseph Peterson. He set up studies with both human and animal subjects in which the factors of both frequency and recency were negative. He found that there was little relationship between frequency and learning and concluded that learning determined frequency rather than frequency learning.

The prevailing view among most competent students of these problems seems to be that if all of the conditions can be properly arranged and controlled, learning takes place very rapidly, even ideally in a single trial. Conditioning, therefore, seems to be an explicandum rather than an explicatio and is open to the serious criticism that even though it were competent to act for many simple instances of learning of the molecular type, it leaves entirely out of consideration factors known to be powerful determinants of the amount, rate, and limits of the type of learning which we have described above as molar.

Psychological Optics
—BY—
SAMUEL RENSHAW, Ph. D.
Ohio State University

OPTOMETRIC EXTENSION PROGRAM

HABIT AND LEARNING

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Our two previous papers were devoted to an examination of conditioned response theory and experiments. They concluded with some comments upon the doctrine of conditioning as a universal principle of learning. For several reasons it is not possible to regard all learning as belonging to the conditioned type of process. The rather simple mechanics of conditioned response theory overlooks the many-faceted perceptual and rational reorganization which marks so many instances of human learning. For example, try to reconcile the theory, in an explanatory way, to Newton s invention of the calculus, or to any of the scores of examples which may be cited where problems are solved by a single brilliant stroke of insight. The effort is never very successful. Conditioning may be an effective means of establishing some forms of surrogatory controls in behavior, it is true. But as a fundamental principle or as "the key that unlocks the cortex and its functions" it is to be feared that the doctrine falls far short.

Before one attempts to examine and accept any theoretical formulation of the mechanism of learning it is wise to review some of the known facts about the nature of learned or habitual acts. Likewise, we must examine some of the essential preliminary causes which relate to the fundamental conception of the means whereby an organism is able to adjust successfully to new and changed conditions of life. Here, as we have stressed previously, the basic theory or point of view, will strongly influence procedure and method and in turn results and interpretations.

"To learn" is an intransitive verb. It does not take an object in the grammatical sense. In general, any living thing learns when it responds with (and never to) sudden enough and important enough changes in its environs by a restoration of equilibrium with a minimal expenditure of energy. Rate of learning specifies the time consumed from the beginning of the disruption of equilibrium between the organism and its surroundings to the establishment of the new, and under the circumstances, best possible equilibrium. The limit of learning is set by the organic competency for such synergy and by the rigor of the demands imposed by the disrupting change in the pattern of the internal external energy gradient.

Learning thus may be regarded as a biological-psychological mechanism which is essentially a form of "eating," or energy collection and transformation, no matter how diversified and differentiated the forms it may take. In living systems it is fundamentally the same sort of function as metabolism, growth, differentiation and de-differentiation, reproduction, and locomotion. In non-living systems it is a physical or chemical change of form and function such that either less energy or more energy may be required on subsequent excitation to produce a coordinate change in form or function. In living systems also the result of any excitation may be either to sensitize or desensitize the system with repeated excitation of an identical or similar sort. It is from this fact that learning selectively transforms the environment in which the organism lives. The change is tantamount to an increase in the excitatory power of certain classes of objects or events, and a decrease in others. The result is a virtual but continuous re-creation of the world as it is perceived and "responded to" which is co-extensive with life itself. Man learns and thus creates his world and himself. It is hardly necessary to point to the impressive magnitude of the artificial, man-made portions of our lives. Our many languages, literatures, science, music, art, laws, habits of dress, eating, sleeping, etc. are all matters of this sort. History is largely the record of the nature and rate of changes in these things. Governments, churches, and schools are agencies we

set up in the attempt to control them. If we were to remove from the Englishman, the Chinese coolie, and the African aborigin, and from ourselves all adventitious habits, we should have left the common factor, often designated as man's common humanity. Likewise, when we consider the infant, we are at once confronted with the problem of nature versus nurture. How much of the ultimate repertoire of acts has been put on due to training and how much can be ascribed to mechanisms which are congenital and inherited?

Only a few decades ago the influence of Darwin, Tyndall, Huxley, and Spencer created the belief that the magic word "heredity" carried the answers to every phase of this problem. A new born child was a bundle of tropisms, reflexes, and instincts. Nothing new could be added by training. The elements of every form of behavior were already present and all that was demanded of learning was the linking together of the smaller parts to make newer, larger functions or to exercise and expand what was already present.

It is quite difficult to gauge properly the harm done by this doctrine of utter determinism. The only hope seemed to lie in selective breeding. Training, or education, could merely play a secondary role.

Today the outlook is quite different. Consider the following quotations from recent books on the subject: "No 'potential character' ever is 'already contained' in anything: and the notion of potentiality, wherever used, is a mark of finalistic thinking. The contents of the germ-cell are not potential characters, traits, or talents, at all, whether bodily or mental: they are actual proteins and other substances, and to call these substances potential this or that is to flout the truth. There are no innate characters. Those persons who imagine that they are dealing with potential albinism, cyclopia, or lethal factor, or with a phobia, herd-instinct or mathematical endowment or ability, will in the end have to give place to more observant investigators who can recognize a carbohydrate or an amino-acid when they see one." (E.B. Holt).

In the fertilized egg growth is not a mere process of unfolding from within. It does not grow, or even continue to live, unless it is steadily assisted by proper conditions of external warmth, moisture, light, and the presence of important nutritive and oxidative substances. Stimulation, irritability, and reactance are matters of the semi-permeability or selective permeability of the limiting membrane; of the destruction and restoration of equilibrium between the cell and its 'constant and correct' surroundings. It cannot and does not live alone. Its entire career depends as much upon where it lives, what cells are its neighbors, even, as upon its own internal chemical organization. Up to a certain level of growth, development, and differentiation, a cell can take on an entirely new set of properties, such as shape, function, rate of metabolism, etc. if it lives in the range of influence of powerful chemical agents produced and disseminated in gradients from other cells.

These concepts--dominance and isolation of parts, gradients of conduction, metabolism, and irritability have forced thinking about the determination of individuality in organisms into wholly new channels.

When 'instincts' were carefully examined they were never found because the doctrine was soon recognized as a surviving form of the ancient myth of intuitionism. The work of C. M. Child, R. S. Lillie, and Paul Weiss has led to the important conclusion that "all organismic patterns are likewise behavior patterns, that is, their realization is not an autonomous action of a protoplasm but the reaction of a protoplasm of specific constitution to an environment." The <u>function</u> of any living thing is therefore as primary as its <u>form</u>; neither can exist without the other. If this is true, learning can be regarded as on a parity with genetics; and it must follow that the hopeful outlook for the future is that when we learn how to train a function perfectly, we may do something with it of great individual and social importance.

Genes and hormones seem to differ principally in the matter of where they are produced--inside or outside of the body. Regardless of their origin, the powerful effects of growth and development are the same. Thus the problem of learning took

a new importance when Child and more recently Weiss showed that "development is a process of functional construction, that is, beginning with a given structure and function, the continuance of function modified the structural substratum, and this in turn modified further function and so on." The notion of growth as a mere unfolding of potential characters must be abandoned. The process of functional construction which is so largely sustained by allonomous agencies is not different in principle from the process we call learning. Organic development, growth, and learning are one continuous process, to the earlier phases of which we give the one name, and to the later phases we give the other. Physical growth and restoration of tissue is mainly a chemical synthesis probably brought about through the agencies of organic enzymes or catalysts. Developmental growth or learning is probably in large measure the work of oxidative, katabolic processes initiated by external stimuli. This distinction should indicate one of several real distinctions between physiology and psychology. To physiology belongs the task of describing the former and to psychology the latter series of events.

The behaviorism of Watson and the conditioned reflex of Pavlov differ but little. Both regard habit or learning as a mere process of the compounding or conjoining of unit reflexes to fabricate newer movement processes. More critical examination of the concept of the reflex has led to a radical revision of our understanding of the real meaning of this term. More particularly it has led to a rejection of the reflex as the basic building material used in the formation of habits. Let us illustrate with a single example.

From the first few days a baby can converge and accommodate its two eyes upon a point in space--say to fixate and follow a small point of light. Is this complex set of eye movements the operation of an inherited or congenital pattern of reflexes? The older view answered by an immediate "yes." There was an assumed point to point correspondence such that a different pattern of moving the two eyes so as to focus the light upon the foveas was set going by each tiny sensitive spot. Experiments have shown that this is not the case. The innervations which the six pairs of extrinsic eye muscles receive in triangulation movements are determined not only by the position of the retinal point which arouse the movements, but also by the pre-existing position of the eyes. It follows therefore that every sensory fiber must possess not merely one connection with the motor nerves, but as many as may be required for all possible positions of the eyes. Thus a pure physiological reflex explanation, taking no account of the influence of what is seen, i.e. the form, size, distance, velocity, etc. of the object--can give us no satisfactory account of these important eye-muscle habits.* We may also point out that the so-called behaviorist is equally open to this same criticism. For if he claims that these sensory-motor connections are set up by training, i.e. by some process of established paths of conduction by use or training, it must be evident that the only difference between this theory and the nativistic one lies in the matter of whether the connections are there from the first or are built up later by training. Neither case can account for the results of experimental observation. The primary function of vision is as a device for assisting, by approximation and correction, in the guidance of hand, arm, and leg movements. Space discriminations, as has been shown by the experiments of Stratton, Ewert, Hunter, Peterson, and others has shown that visual space is as much a matter of posture and of movement as it is of retino-cortical excitation. Marina surgically crossed the extrinsic eye muscles of a lemur and the animal was later permitted to use his eyes for localizing external objects. The eyes coordinated in convergence perfectly. The logical explanation on the basis of the older theory would have demanded a bewildering series of saccadic and strabismic fixations.

In this as in numerous other instances which could be cited, the blind non-directional function of the reflex as the basic mechanism in habit formation is found wanting. Forty years ago, William James, in picturesque language, described habits as "hoops of steel" and invariant: not only second-nature, but "ten times nature." For him the mechanism of simple habits was "to deepen old paths or make new ones" in the brain. To quote further, "the most complex habits.....are.....

nothing but concatenated discharges in the nerve centers, due to the presence there of a system of reflex paths, so organized as to wake each other successively--the impression produced by one muscular contraction serving as a stimulus to promote the next, until a final impression inhibits the process and closes the chain." In sharp contrast to the Jamesian statement as to the nature of habit--still held, unfortunately, by altogether too many educated people--we may contrast the work of K. S. Lashley, who has shown by many experiments that a habit depends upon the amount of functional cortical tissue and not upon its anatomical specialization. Simple habits of sensory discrimation are formed without apparent change even when the entire sensory field of the brain is removed. No differences in maze learning were observed after lesions in different cerebral areas and the retardation in learning due to the loss of brain tissue up to 60% was not referable to any sensory defects. Lashley concludes that the learning process and the retention of habits are not dependent upon any finely localized structural changes within the cerebral cortex. Lashley's many experiments are "incompatible with theories of learning by changes in synaptic structures or with any theories which assume that particular neural integrations are dependent upon definite anatomical paths specialized for them. Integration cannot be expressed in terms of connections between specific neurons. In the brain there is not a summation of diverse functions, but a non-specialized dynamic function of the tissue as a whole. The mechanisms of integration are to be sought in the dynamic relations among the parts of the nervous system rather than in details of structrual differentiation.

* This illustration is from the late Dr. Kurt Koffka.

Psychological Optics

—BY—

SAMUEL RENSHAW, Ph. D.
Ohio State University

OPTOMETRIC EXTENSION PROGRAM

HABIT AND LEARNING
(Part II)

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Whenever the demands of living must be met by putting on a new movement, the first attempts are marked by movements that are spastic, jerky and incoordinate. Likewise if a new object is shown an observer for the first time, the search for meaning will run a course strikingly parallel to that demand enforced upon the motor or executant system of the body. In either instance it will be noted that the reactor does too much; too many muscles come into play. They hamper and interfere with one another. In the search for meaning speculation may run rife. Analogic reasoning often goes to extremes and a welter of inferences present themselves. Usually these are too complex, too manifold, and the process of arriving at a satisfactory resolution of the issue is effected by a reduction, simplification or attritional procedure.

There is a significant and quite striking similarity between the steps taken by a person in the verbal solution of a problem ("reasoning" or "thinking") and in the manipulatory solution of a similar blocking case. Indeed it is a moot question psychologically as to whether one is ever justified in setting up any such dual categorical classification as the one implied above. It is more likely true that in the final analysis all verbal solutions are at the heart motor and manipulatory, and what we designate as reasoning or thinking is merely surrogate linguistic mechanics used in foreshortening the basic original means of accomplishing a satisfactory bio-social adjustment.

Every learning operation represents a more or less continuous reorganization of the individual s attack upon his problem in which variation in procedure is always contingent upon his proper understanding of the demands of the situation and his judgment as to what is to be done about it in order to consummate the most effective adjustment.

Now let us clearly remember that in life many skilled movements must be learned which are clearly perceived as totalities but which are utterly incapable of verbal or other linguistic representation. These movements cannot be localized. They cannot be ascribed spatial position. They cannot be given any communicable name or names. From, or possibly even before the moment of impact of club head and ball, a golfer, for example, "feels" the perfect stroke, "run right up his left arm." Yet he is unable to tell precisely how or why this stroke differed from the one before which yielded an indifferent (or worse!) result.

In perception, as in skilled movement, the consummate act which is skilled is a unitary process. It cannot be analyzed into component parts without distorting or destroying it. By the same token it cannot be synthesized out of smaller unitary part processes. The swimmer does not learn to swim by first mastering the special movements of his feet in the kick; then the arm movements; then the head and breathing--the correct form must be achieved as a unitary form. Obviously the difficulty in this achievement is due to the fact that immediate sense perception of the proper form is rarely to be had. It is for this reason that we must "practice." And "practice" is but another way of saying that we arrange conditions as best we can to permit the effectual reorganization of the form of the movement into that which we wish it ultimately to be. So obviously one of the very first steps in the control of any learning operation is to get the learner to clearly understand just what it is he is to be expected

to do. This can usually be done by demonstration--or a combination of demonstration and 'explanation'. Rarely can this alone suffice, but through his own efforts he can be brought to appreciate the objective.

Observation of how a skilled performer does it is not usually very fruitful, since it is so hard to <u>see</u> even a simple movement in demonstration and be able to reproduce it. Consider how long the medical student must "practice" until he can tie neatly and quickly the surgical knots; can sew the stitches and achieve the technique of the master-teacher with the scalpel, even though he watches carefully the same strokes day after day. Some never can do it. To letter perfectly with a pen means first you must <u>see</u> perfectly the shapes of the letters you are to reproduce.

Learning in such case is a process of replacing the visual control of the hand movement with the tactual, kinaesthetic and articular cues which derive from the movements themselves. Let him who thinks the process of copying to be an easy one try it. An interesting and important result may be seen in the conventional multiple-choice experiment in the laboratory. The apparatus is a black box the size of a suitcase. From one side, facing the observer, twelve keys extend like piano keys. In the open lid making a screen is a ground glass disk behind which a red lamp flashes indicating error, and a green lamp indicating a correct response. Any or all keys may be made disposable to the subject in any setting. The object is to learn to press the correct key to sound a buzzer or light the green light on the first choice or trial. Suppose for example five keys are extended. Counting from the left, keys 1 and 2 are depressed in order and each time error is indicated. When key 3 is depressed the light is green and the buzzer indicates the correct response has been given.

The keys are now withdrawn and nine keys are extended. What is the logical first choice? Key 3 from the left--or was it the middle one of the group of odd numbered keys? Or may there be some other principle? The object is to discover a "rule" or "law" to enable one to press the correct key the first trial no matter what the number or pattern of keys disposable.

The learner must do something more than 'try, try again'. It is not uncommon to find that capable students will frequently press the correct key on twenty successive settings and yet be utterly incapable of formulating in words the generalization or "law" which governs that particular problem. One may or may not learn by doing. It does not follow that even a simple manipulatory skill is immediately and automatically transposed into representative terms. Nor does it follow that merely by watching a skillful performance we can transpose what we have seen into acts of our own. Even the simplest movement is far more complex than most persons have any notion. Take for example the first letter of the English alphabet: A. Transpose it into sound with your vocal apparatus and there are at least fifty possible variants. When the articulation of this primary vowel sound is made it is found that many muscles of the body assist in the tone production--the whole "simple" process is one of unbelievable nervous and muscular complexity.

Fortunately within the last few decades great progress has been made in research leading to a better understanding through the analysis and study of skilled voluntary movements. One of the most important generalizations from the work of Beaunis, Richet, Stetson, Dodge, Bott and others is that an act or movement, no matter how simple, that is skillfully done is a different kind of a movement from "the same" movement done by a novice or a beginner who is untrained. I have found that the same generalization holds for the difference between the process of perceiving in a trained subject compared to an untrained subject. Humphrey and others have shown that the eyelid reflex, when conditioned to an 'artificial' stimulus is a new and different movement. Its latency, susceptibility to summation, extinction, etc. are radically changed.

When a simple movement is made by an untrained person the movement has the properties of a <u>tension</u> movement. Antagonistic muscle groups contract against

each other and the contraction is coextensive in time with the movement itself. The movement runs a jerky, spastic, erratic course and comes to a stop by the more or less sudden contraction of braking antagonists. The vector or course of the movement is a sort of resolution or algebraic summation of antagonistic forces. Too much energy is expended. It is wasteful and tiring. Accuracy, neatness and skill are low. Repetition alone will not change it over into a skilled movement. This change may come in the course of repetitions but certainly not because of them. Now let us look at what is socially called the same movement done with skill.

We note that the movement now differs radically--it is not the same movement in any property or characteristic. Here the muscle contraction is instigated from a low rather than a high state of tonus. The muscle contracts in about .050 second and throws the limb into activity, the movement itself is ballistic or ballistiform--smooth flowing and easy and its course swings through and comes to a stop without the braking action of antagonistic muscle groups. In drawing, bowing a violin or swinging an iron in golf, the movement of the virtuoso or highly skilled performer is smooth, accurate, easy, non-fatiguing. The motor function is freed from sensory interference, and it is likely that the inhibitory influence of cortical activity on all lower level functions of the central nervous system is minimized in such case.

The eye movements of a poor reader are spastic, regressive, tension movements. Those of a well trained reader flow easily across a line of print without abrupt pauses, and more important there is no motor dampening or erasure of the visual sensory impression. In ocular pursuit movements this skill, or the lack of it, is particularly important. Can any lens application be done properly without first a careful check and any indicated functional repair work properly done? Let those who operate upon the sole basis of physical and physiological optics give some thought to the essential relations of posture and movement to such matters as acuity and resolution, fusion, etc. Training of the proper sort is just as important a phase of ophthalmic and optometric service as that subsumed under the term "refraction." Actually a large portion of "refraction" has nothing whatever to do with the measurement of a light wave-front bent in passing through the mediae. How much "refracting" can you do upon a completely immobilized eye detached from the neuromuscular system of its possessor?

How does a tension movement become replaced by the ballistiform skilled movement? Is the rate of progressive development steady and constant or is it saltatory? Is there a clearly marked zone of transformation or is there evidence even in the early trials or practices of the beginnings of skill? What is the optimal set of conditions for the acquisition of skill?

Questions like these can only be answered by careful and painstaking research. Some of them are in various stages of answering at present and some are still to be classed as unknowns.

We shall address ourselves to questions of this type in the series of papers to comprise Volume 4. None of us can predict the future. Efforts devoted to helping to win the war increase almost daily. There seems to be a desire of some for us to continue this series. We shall carry on as best we can.

Psychological Optics

—BY—

SAMUEL RENSHAW, Ph. D.
Ohio State University

 Duncan, Okla.

OPTOMETRIC EXTENSION PROGRAM

LEARNING

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We come now to the last of the third series of papers. It is fitting and proper that we give some consideration to the general fact that no other property is so characteristic of human behavior as that which we may call adaptability. Alfred Binet, the famous French psychologist, one time defined intelligence as the ability to meet, adequately, new and changed conditions of life. No other living thing possesses this capacity in comparable degree to man. This means that rapid and satisfactory readjustment of behavior patterns to new and changed conditions of life cannot be a mere stereotype produced by random repetition. All organic patterns are in constant change. Development, differentiation, and dedifferentiation are going on continuously. To meet the test of adequacy, the process of change must be rational and understanding. It must proceed according to plan. The learner must constantly take stock and revise and amend his modes of attack upon any problem if he is to achieve the maximum return for his expenditure of time and energy.

It is easy to see that all learning is essentially an energy-saving device in the biological world. The learned act is consummated smoothly, quickly, and almost without effort. In contrast, the unlearned movement is jerky, spastic, and tense, and is generally characterized by excessive and wasteful expenditures of energy. Whatever the process involved, it is certain that the process of learning is always marked by a progressive diminution of the energy required to consummate an act. It should be clearly borne in mind that the learned act is not a mere reduction in complexity of the incoordinate movement of the beginner. Nor is it a mere addition of new components brought about by repetition. The concensus of many investigations seems to be that learning is a process of replacing scattered and antagonistic movements of singular character by a new kind of unitary function possessed of markedly different properties and characteristics. The trend in habit is precisely the same trend seen in acts of perceiving, namely, the tendency toward nonspecificity, toward abstractions and generalizations.

The net result of widespread research activities to the present seems to indicate that the proper understanding and control of learning does not lie in the conception that learning is a mere refinement or concatenation of elemental reflexes. Rather, we must take the view that it is a much more complex reorganization of the whole organic pattern. If learning is assumed to be a function localized in one segment of the body, we know that its course will be materially modified by concurrent activity at other neurol muscular levels (Dodge). If this is true, then as Peterson pointed out a number of years ago, the process of learning is not a mere process of the establishment of new conduction pathways in the nervous system, because such a conception would leave practically nothing for the effector apparatus to do except to obey the irrational mandates of the volleys of ions discharged from the motor nerves. I have pointed out previously that many studies have indicated that the muscles and the glands impose backward upon the central nervous mechanism a certain selectivity which is as important for learning as the qualitative and quantitative sensory components in the pattern. It is not unlikely that we shall be forced to take the point of view that all organic functions are susceptible to reorganization through practice or training even though at present some of them seem to be stable, fixed, and incapable of such adventitious change. The likelihood is that these functions which have thus far resisted our efforts to train them are not functions insusceptible to practice effects, but merely functions which have failed to improve because of our own ineptitude in devising adequate and appropriate training conditions.

The hope of the future of humanity lies in exacting the last degree of operational competency from human beings, by the use of the best methods which science is able to devise. Learning has only been studied scientifically for about a third of a century. It is, therefore, a new thing and many aspects of it are still untried and unknown, but the unknown land is one of rich promise as experimental achievements have amply demonstrated.

In the practical case we want to know what can we do to properly control the learning process? What do we know about learning which can be turned to good account in our everyday experiences? Hardly a day passes but every man who reads these lines sees a patient whose vision is in definite need of repair through appropriate training. What shall be do? How shall we proceed? Let us examine a few of the generalizations which have come from the laboratory investigations of learning and see to what extent they may furnish us with guiding principles in the adaptation of orthoptic procedures used in visual rehabilitation. We shall do this by setting down a series of statements or generalizations which psychologists largely accept as true. If documentary substantiation is desired such would require bibliographic citation of several thousand monographs and technical articles. It is hardly proper to designate these statements as laws of learning, they are largely generalizations based on the experience and results secured by many able students of the problems of learning. In a way they may be regarded as advise to be given both to the learner and to the person responsible for controlling the course of learning.

1. Practice in the manner you wish ultimately to perform.

This means that when a baseball team is practicing for a championship game, practice should never be listless or haphazard. The ball should be handled and thrown with the same speed and accuracy as if the winning of the pennant depended upon every play. If one is learning to speak English properly, practice should not be construed as Sunday manners or as a thing to be used only on occasion. If the eyes are to be trained to fixate, to converge, or to follow a moving target smoothly, the training procedures and devices should be adapted to develop these movements so that they function identically with the manner in which they are to be ultimately used.

2. The learner must expend effort and truly want to improve.

It is by no means trite to say that learning can only be done by the learner himself and that if real progress is to be made it must be accomplished under the appropriate circumstances, that the learner through effort reconstructs the activity patterns he is seeking to perfect. Every good teacher knows that time spent in laying the foundation for learning by bringing the learner to the proper state of attitude even before any practice is indulged is the wisest possible investment of his own time and energy.

3. Do not practice too much at any one time.

It is wise to always stop a little short of fatigue or boredom. It is wise, also, to realize that the ultimate aim in learning is to secure proper form of the function. Learning is not a mastery of mere content. Consequently, it has been found that, particularly in the early stages of training, the maximum attention must be given to the important business of setting the learner in the proper form, so that he may perceive something of the thing he must ultimately do with ease and skill. The amount of daily improvement that individuals may effect from practice is quite variable. For even superior learners, in the case of some functions, this amount may be small. Particularly is this true, if the skill to be acquired is hampered and interferred with by older habits which are antagonistic to the new movement. Likewise, it should be remembered that it seems probable that true learning goes on as much or more in the intervals between practices as it does during the practice sessions themselves. This leads to the next statement.

4. Distribute the practice with appropriate rest between.

We know that in the acquisition of certain manipulatory skills, three practice sessions a week, for example, will produce more satisfactory and more rapid improvement than daily practice sessions. If we wish to secure the maximum amount and rate of im-

provement, it is necessary for us to properly balance the length of each training session and the distribution of these sessions in time, so that we may take full advantage of what James one time called the "incubation principle." This says merely that we learn to skate in summer and to swim in winter. If we overcrowd the practice, we vary the stimulus response patterns at the time when the reorganization of the after effects of previous practices are in process. Thus, when we try to go too fast we merely undo the positive gains from the immediately preceding practice sessions.

5. Repetition does not produce learning, but merely presents sufficient opportunities for the reorganization of the process through approximation and correction.

Theoretically, if all the conditions, internal and external, in the learning situation could be ideally controlled, it is likely that learning would take place in a single trial. The difficulty is that the conditions are too complex and variable to achieve this ideal. From this point of view, the number of practices becomes less and less important, and the "quality" of the practices more and more important.

6. The proper form of any skilled movement is achieved by what has been called "the unconscious adoption of method."

This means that in learning the golf stroke or the proper bowing of the violin, the learner cannot watch a virtuoso perform and reproduce in his own muscles the same pattern of movement. He tries again and again and makes errors, which by the process of approximation and correction he eventually is able to replace by the proper movement. This discovery must be made by the learner himself. It cannot be taught or communicated by any known means.

7. Do not expect miracles. Some skills take time to acquire.

Even a simple movement on analysis is found not to be simple at all. To master such a movement may mean weeks, months, or years of laborious practice and training. The question becomes one really of what level one is willing to accept as a satisfactory approach to perfection. Our social standards for many common habits are low. We accept bad habits of handwriting, speech, posture, and walking, whereas, we refuse to accept similar standards for cleanliness and so on.

How long should it take, for example, to retrain a squinter to posture his eyes properly? Obviously, no catagorical answer can be given to such a question. Also, obviously, the ultimate success of such an undertaking will depend upon the same considerations we have discussed above.

8. Avoid practice in error.

This means that if a person is attempting a new and better way of doing some thing, every effort should be made in the practices to prevent the occurrence of error-producing movements. There is little doubt that the slow rate of improvement in the acquisition of many skills may be attributed to the fact that both good and bad habit mechanisms are being set up concurrently. When the professional baseball player goes into a hitting slump which may last for several weeks, it is not at all unlikely that he is merely resorting to a less expedient method of attack or to a definite habit pattern less productive of base hits. The change may be so slight that he is unable to tell what he now does which produces the undesirable result. The return to normal hitting performance occurs overnight, without warning, and has yet to be explained.

9. Work "with knowledge."

This means that the learner should be informed of his progress. Knowing the effects produced by any movement enables him to revise his mode of attack and to perfect that superior form which gives the better result.

10. Review and practice in recall is highly effective as a learning device.

Psychologists who have studied this problem advise that for the maximum return, if one were to spend a hundred units of time and energy in study or learning, more than half should be spent in this sort of rehearsal.

11. Introduce theory and analysis only

after training has reached a relatively advanced stage.

Experiments have shown that the sure way to retard the progress of learning is to build up an elaborate linguistic framework from theoretical reading and study in advance of contact with actual performance.

12. Habits may interfere with one another or may reinforce one another.

Whether interference or reinforcements follows, seems to depend upon the stage of perfection of the older habit.

13. If more than one habit is being learned simultaneously, the rate of learning will be diminished in proportion to the number and complexity of such habits.

This means that in learning a series of diverse unitary functions, it is better to reduce the number, and thus prevent wasteful interference.

14. Be sure that the learner understands clearly what is wanted or expected of him from the very first.

15. Realize that a learned act is a unity and is not made up of smaller part processes or movements learned singly.

16 Develop early self-confidence by permitting the learner to progress only as rapidly as he can, never crowd or hurry him. Nothing succeeds like success.

(To be continued)

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DATE DUE	BORROWER'S NAME